NUMERICAL ANALYSIS OF GEOCELL REINFORCED EARTH RETAINING WALL

A Thesis submitted in partial fulfillment of the requirements

for the award of the Degree of

Master of Technology

in

Geotechnical Engineering

Civil Engineering Department

by

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MAY 2015

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CERTIFICATE

This is to certify that the thesis entitled "**Numerical Analysis of Geocell reinforced earth Retaining wall**" submitted by **Mr. Vippagunta Ravi Teja** (Roll No. 213CE1053) in partial fulfilment of the requirements for the award of Master of Technology Degree in Civil Engineering with specialization in Geo-Technical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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ACKNOWLEDGEMENT

I would like to express my heartfelt gratitude to my project supervisor **Dr. N. Roy**, Professor, Department of civil Engineering for his able guidance encouragement, support, suggestions and the essential facilities provided to successfully complete my research work. He offered me the possibility to work in a liberal environment and given me the freedom to carry out my research in an independent way.

I sincerely thank to our Director **Prof. S. K. Sarangi** and all the authorities of the institute for providing nice academic environment and other facilities in the NIT campus. I am also thankful to all the faculty members of the Civil Engineering Department, especially Geo-Technical Engineering specialization group who have directly or indirectly helped me during the project work. I would like to extend my gratefulness to the Department of Civil Engineering, NIT ROURKELA, for giving me the opportunity to execute this project, which is an integral part of the curriculum in M. Tech program at the National Institute of Technology, Rourkela.

Last but not the least, I take this opportunity to express my regards and obligation to my family members for encouraging me in all aspects for carrying out the research work. I am deeply grateful for the support from some Ph.D. scholars of Mining Department, and my friend who taught me the software at the right time and the help from my colleagues and friends who are at my side during the research work.

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ABSTRACT

Now-a-days usage of concrete in the field of civil engineering is increasing rapidly in which most of it is going as waste due to improper management and care while placing it. The waste produced cannot be recycled/reused, so as to eradicate this some alternatives can be chosen. Mainly in the construction of retaining walls, concrete panels are used to support the backfill soil, but at the time of installation most of the panels get rejected because at the time of transportation and installation of panels. If proper care is not taken the ends get damaged by which there cannot be a proper bonding between the adjacent panels. So as to overcome this geocells are used in case of concrete panels which is a HDPE (High Density PolyEthylene) material which is a reusable can be used under any climatic conditions, transportation and installation of this material is easy and consumes less time. Geocells are placed in layers one above the other as the depth of geocell is restricted, so all the layers are placed with some inclination as it is easy to support backfill soil and the displacements generated among them can be encountered. Analysis of geocell reinforced retaining wall is done in PLAXIS 3D. PLAXIS 3D is a finite element analytical geotechnical software gives accurate results compared to that finite difference and limit equilibrium analytical software's. In the PLAXIS 3D software, generation of geocell retaining wall models with inclinations are made and without load and with loading conditions. The results obtained from the analysis are collected and compared among themselves and from the comparison the retaining wall with a specific inclination which ever gives better result is suggested and some different arrangements of geocells are made with the suggested angle and results are analyzed.

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 ORIGIN OF PROJECT

To resist the lateral pressure of soil and if there is any change in elevation of ground exceeding the angle of repose of soil then retaining walls are constructed in order to prevent them against failing. There are many number of ways by which we resist the soil against failing i.e. by constructing gravity wall, cantilever wall, pile wall, anchored wall, soil nailing, gabion meshing, cellular confinement. Now-a-days the conventional method of constructing retaining wall is by installing concrete panels with addition of geogrid or by geosynthetics fixed at the ends of panels. So due to the extensive usage of concrete, an alternative must be choose because at the time of manufacturing or installation, if the panel breaks it cannot be utilized and concrete cannot be recycled which in turn gets into a solid waste. So in order to overcome the better alternative is using *"Geocells"* for constructing the retaining wall, as it is easier for transportation and installation point of view and there is no need of recycling. Because no damage will be achieved by which we can use at any appropriate place without any major effort. Usage of geocells suits better in cold weather conditions compared to that of concrete panels, as concrete panels require more attention to sustain cold weather. Geocells are generally made from high-density polyethylene (HDPE) or polyethylene (PE) strips, which are ultrasonically welded along their width to form three-dimensional cells. Cells are filled with soil or stones that have good strength by which load taken by backfill soil will be increased compared that of load taken by concrete panels.

R.J. Bathurst et al. (1993), O. Al Hattamleh and B. Muhunthan (2006), R.H. Chen and Y.M. Chiu (2008), Nicolas Freitag et al. (2011) and Che-Wei Shen et al. (2013) have performed various studies, experiments and numerical analysis related to geocell and geostrip retaining structures. In the above studies, design and construction of geoweb which is similar to that of geocell are described and experimental analysis of geocell retaining wall are made from which settlements are found for different facing angles in this analysis a model of retaining wall was made and instead of geocell a thick sheet of paper was provided as reinforcement. Some of the studies also include the finite difference numerical analysis in which geostrip are installed in mechanically stabilized wall and respective settlements are found and compared among themselves.

1.2 PRESENT STUDY ELEMENTS

R.H. Chen and Y.M. Chiu (2008) had made the experimental analysis on geocell reinforced retaining structures to examine the effect of the geocells and their failure mechanisms under surcharge conditions. The main elements included in this test are facing angle of structure, type of surcharge and the type of reinforcement material used in the experiment. So accordingly numerical analysis is made by considering the software PLAXIS 3D.

PLAXIS 3D is a finite-element analysis software in which engineering problems in the field of geotechnical engineering and design are solved. It constitutes of a computer program package for finite element calculation of stresses, strains of structures and foundations, etc.

So as it is a 3D software all the models are to be constructed in the three dimensional point of view and certainly the analysis can also be done in the direction whichever is required, by using 3D software it helps in eradicating some of the assumptions and the analysis whichever made will be precise when compared to that of analysis in a 2D finite element software.

PLAXIS 3D software is generally used for analysis of soil and rock in which different soil models can be considered and their corresponding characteristics are entered and simultaneously analysis is done.

1.3 OBJECTIVE AND SCOPE OF THE PRESENT WORK

The main objective of project is to decrease the usage of Concrete panels in retaining earth walls by replacing it with geocells filled with soil & stones and to find out a facing angle of retaining wall with respect to horizontal which gives better result.

The main scope of the present work are:

i. To generate models of geocell reinforced earth retaining wall for which the facing angle of retaining wall makes an angle of 60º, 70º, 80º and 90º with the horizontal respectively.

ii. Numerical analysis of the above models using the software PLAXIS 3D and interpretation of results.

iii. From the above analysis, the model which gives the better result will be modified using three different layouts and will be analyzed using the same software.

The three different layouts indicated below are:

a. Retaining wall consisting of several zones in which all the zones will have equal number of geocells.
b. In the upper part, geocell layers are extended to prevent the wall from getting it tilted.
c. Geocell layers were lengthened at certain depths, to act as reinforcements and to enhance stability. The increase in the length of geocells can be regarded as providing reinforcements similar to that of geogrids.

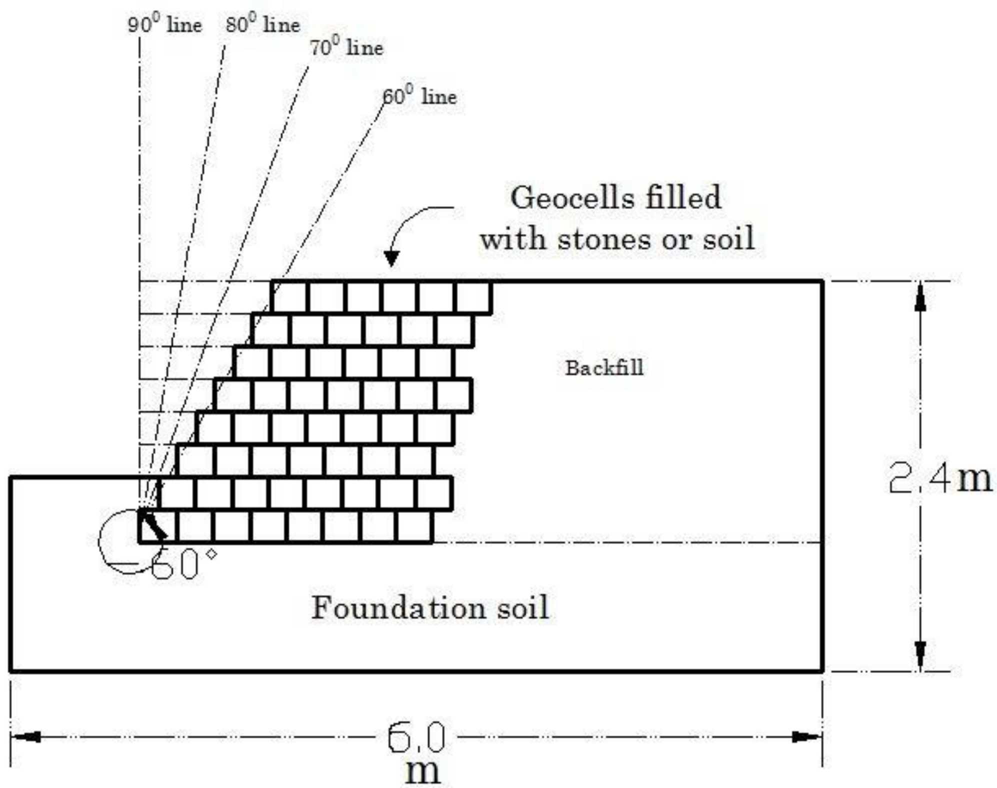


Fig. 1.1: AutoCAD layout of the retaining wall model with different facing angles in a 2D view indicating geocells and soil

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

This section discusses about the background information of the issues regarding the present research effect and focus of the significance on current study on elements such as geocell reinforced retaining wall, geostrips and deformation analysis and about the software PLAXIS 3D.

Literature on geocell retaining structure:

Bathurst,R.J. et al. (1993) reported a paper on case study which described the design and construction of a 3 m high Geoweb retaining wall comprising 520 sq.m. of face area which was constructed to support a sloped backfill.

Al Hattamleh, O. and Muhunthan, B. (2006) presented a paper on membrane analogy method to evaluate the deflection of fabric-reinforced earth walls.

Deflections of the wall were evaluated by two methods:

i. Some resulting equations which were obtained while analyzing were solved using a finite difference scheme to obtain the deflection and
ii. By the software FLAC which is a finite difference program, numerical results are obtained and those are compared with the results obtained from equations.

Chen, R.H. and Chiu, Y.M. (2008) published a paper which described the deformation of the wall face and the backfill settlement and concluded that both got increased with increasing facing angle and surcharge. For gravity type, the maximum lateral displacement occurs at the top of the wall and two failure modes can be observed, interlayer sliding and overturning. For the facing type, due to its being lighter in weight, results show more displacement & settlement.

Nicolas Freitag et al. (2011) prepared a paper to determine the internal behavior of a mechanically stabilized earth wall in which the reinforcement of the wall is given by 3 different strips by considering 3 individual models and the results obtained from them are studied and compared. Factors affecting the reinforced soil mass are also studied.

Che-Wei Shen et al. (2013) presented a paper on analysis and verification of three numerical model-scale gravity-type walls with different facing angles. The structure that extends the length of geocells in some layers to serve as reinforcement performs well in reducing the deformation of the structure and decreasing the potential slip zone. The obtained results are compared with the results which are obtained by experimental analysis which were made in the year 2008.

Damians, I. et al. (2015) had discussed a paper on influence of choice of FLAC and PLAXIS interface models on reinforced soil–structure interactions in which it gives us information about the choice of structure element to simulate soil reinforcement and soil–structure interaction details for numerical modelling of mechanically stabilized earth walls which can have a significant influence on numerical outcomes. Both programs use different models and properties to simulate the mechanical behaviour of the interface between dissimilar materials.

CHAPTER 3

THEORY

3. THEORY

3.1 INTRODUCTION

Geocells are generally made up of high-density polyethylene (HDPE) or polyethylene (PE) strips and are ultrasonically welded along their width to form three-dimensional cells. The obtained three-dimensional cells contains soil or stones. Due to this packing of fill material in geocells, it improves granular soil's shear strength and by this increased soil strength provides improved bearing capacity of soil and prevents soil erosion. Geocells can be transported easily and installation can be done quick compared to that of installation of concrete panels. To improve the amenity of the surrounding environment vegetation can also be planted into the cell. The geocell retaining wall can tolerate the deformation or settlement due to flexibility.

In very steep slope applications where it is not feasible to place panels on the slope face, soils can be retained with a vertical wall structure with the help of geocells. Geocells can be used in two ways i.e. in one case for holding the soil and in the other case to provide drainage throughout the structure.

3.2 SPECIFICATIONS OF GEOCELL

Envirogrid is one of the manufacturing company which manufactures geocells, the specifications of geocell considered in modelling of retaining walls are obtained from Geo Products Envirogrid.

The specifications of the geocell are mentioned below:

Table 3.1: Specifications of Geocell

S.No.	Parameter	Description
1.	Name of Geocell	EGA20[2]
2.	Material	HDPE
3.	Available Colours	Black, Green and Tan
4.	Area of each cell	289 cm^2
5.	Depth of each cell	200 mm
6.	Length of each cell	225 mm
7.	Configuration of geocell	Honey comb shaped

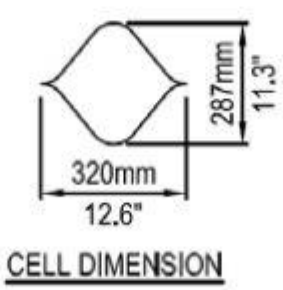


Fig. 3.1: Top view of a honey comb shaped geocell

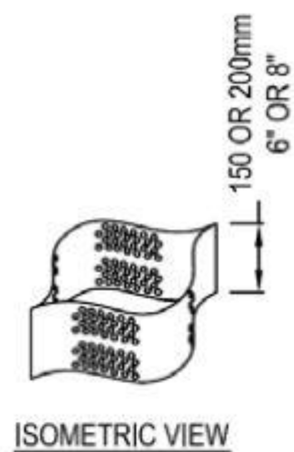


Fig. 3.2: Front view of a honey comb shaped geocell

Fig. 3.3: Geocells arranged in order and filled with fine material on one side and with stones on the other side.

The soil which is filled in geocells and the soil filled in backfill soil is mostly sand, such that as the thickness of geocells are very thin, area occupied by geocells are very less than the area occupied by that of sand. So the friction between sand geocells is mostly negligible or zero.

3.3 ADVANTAGES OF GEOCELLS

The benefits of Cellular Confinement System over concrete panels:

- Reduce Fill Required – With the use of geocells, fill quantity can be reduced by up to 70% while maintaining bearing capacity and mean while saves time, transport, and material costs.
- Eliminate Rutting – Prevents the lateral movement of infill and lower quality fill materials can also be used since they are confined within the cells.

- Support Heavy Loads – Improve the bearing capacity of subgrade soils and extend the life-cycle of the road.
- Quick & Simple Installation - Without any specialized equipment or crews it can be installed easily and quick.
- Utilize Local Fill – Mostly local soils are used as fill so as to minimize transportation costs and installation time.
- Perforated Cells – Due to the help of perforations, it allows the water to drain freely through the aggregates or soil.

3.4 CHARACTERISTICS OF SOIL MATERIALS

- The soil considered for filling the geocells is "uniformly graded dense sand"
- Backfill of geocell retaining wall is filled with "well graded loose sand"
- The foundation soil is considered as "elastic linear soil" so as to know the behavior of stresses and displacements in backfill soil as well as in the geocell fill soil in combination with geocells.

As Geocell fill soil and backfill soil consists of sand, the material model considered for analyzing it in software is "MOHR COULOMB" model and their properties such as Young's modulus, Poisson's ratio, Unit weight, Friction angle, Dilatancy angle and Cohesion are to be entered whereas for foundation soil it is considered as a "Elastic Linear" model and corresponding properties such as Young's modulus, Poisson's ratio, Unit weight are to be provided.

The characteristics of soil materials are mentioned below:

Table 3.2: Characteristics of soil materials

Property	Reinforced fill soil (Geocell fill)	Retained backfill soil	Foundation soil
Constitutive model	Mohr Coulomb	Mohr Coulomb	Elastic Linear
Young's modulus (MPa)	60	24	200
Poisson's ratio	0.3	0.27	0.25
Unit weight (kN/m^3)	17.13	15.72	19.62
Friction angle ($^\circ$)	40	33	-
Dilatancy angle ($^\circ$)	10	0	-
Cohesion (kPa)	1	1	-
R_{inter}	0.7	0.7	0.8

3.5 PLAXIS 3D

3.5.1 DESCRIPTION

PLAXIS 3D version 2013.01 is a user friendly geotechnical program which offers flexible and operable geometry, simulation of staged construction and a reliable calculation package, and comprehensive and detailed project generation, making a complete solution for geotechnical design and analysis.

3.5.2 ANALYSIS

PLAXIS is a finite element analysis program in which three-dimensional analysis of deformation and stability of different geotechnical problems will be carried out. Generation of modelling of soil can be done by using two modes namely soil mode and also in structures mode. The staged construction mode provides simulation of construction and excavation processes by which activation and deactivation of soil volumes and structural elements, load application, effect of water table, etc. can be done. Plaxis output enables us to know the deflections, strains, factor of safety, etc. of the analyzed problem.

3.5.3 IMPORTANCE

In PLAXIS programming the model generated in soil and structures mode are made into tetrahedron elements in which there may contain nodes and based upon the nodes mesh generation is going to take place. Due to creation of the nodes the analysis at any particular can be known, the entire model is made into triangular elements and nodes, but where as in case of finite difference programs the basic element is a square or rectangle by which the nodes at the ends cannot be formed exactly. When there is a comparison between finite element and finite difference, finite element results will be accurate over finite difference results.

3.5.4 POINTS THAT ARE TO BE CONSIDERED FOR GENERATING RETAINING WALL MODEL IN PLAXIS 3D

- As mentioned earlier, geocells are very thin and area occupied by geocells is very less when compared to that of area occupied by the geocell fill, so while designing the retaining wall, geocells are indicated with structural elements that are present on the surroundings of geocell fill soil, by which the geocell fill gets packed between geocell elements.

- Geocells are considered as Geogrids in structural elements and concerned properties are assigned.

- Boundary conditions of retaining wall model:

  In the PLAXIS 3D software there is no need of assigning boundary conditions, it automatically takes it into consideration. But the general boundary conditions are bottom boundary is fixed against movement in all directions and vertical boundaries are restricted in horizontal direction and free to move in vertical direction.

- The shape of geocell element considered in analysis is a square tube as generation of a honey combed shaped geocell in a 3D view is difficult. The dimensions of honey combed geocell are adjusted to the dimensions of the square tube.

CHAPTER 4

ANALYSIS AND DISCUSSION

4. ANALYSIS AND DISCUSSION

4.1 STEPS INVOLVED IN GENERATION OF GEOCELL RETAINING WALL MODEL

Step 1: In the project properties, dimensions in the x and y direction are to be entered, in this case those are entered as 6 m and 4 m respectively. So beyond this model cannot be extended.

Step 2: Co-ordinates of the retaining wall which are to be constructed are known so as to make it easier at the time of modelling. As the modelling is in 3D, so three dimensional co-ordinate are to be noted.

Step 3: In the model generation, we have 5 elements to be generated in which 3 elements are volumes consisting of soil, 1 element is geogrid consists of geocell and other layer is surface consists of surface load on the top surface of the wall.

Step 4: Three volumes of soil are to be generated. In the retaining wall, the three soils namely are the geocell fill soil, backfill soil and the foundation soil. To construct a geocell fill soil as the volume of the soil is in non-horizontal layers so it is constructed in "Structures" mode, so it is skipped from "Soil" mode to "Structures" mode. In the "Structures" mode "Create surface" tab is selected in the "Create surface" tab "Create surface" option is selected. Now the co-ordinates of the geocell fill soil noted in the initial stage are entered in x and z directions so that a surface of geocell fill soil is created in xz plane. In creating the surface all the end co-ordinates (3D) of the surface should be entered in the command line so that after entering the commands a closed surface should be obtained.

Step 5: Now using "Extrude Object" option in the "Structures" mode, the created surface is selected and is extruded in y-direction with a length of 4 m. So that finally a volume is obtained and the surface which was initially created is deleted. So as to assign the soil, using “Show materials” option in “Structures” mode, in the set of “Soil and interfaces”, “New” tab is selected and properties of the soil such as material model, modulus of elasticity, poisson’s ratio, cohesion, angle of internal friction, angle of dilation and the interface value are entered as per this generation of model is considered.

Step 6: After entering the properties of soil, now to assign this soil to the volume, the generated volume is selected and right click is given in which soil option is available and in that option the soil added formerly is shown and with a click on it soil is assigned to the generated volume.

Step 7: Similarly in the procedure of the generating the geocell fill soil volume, backfill soil and foundation soil volumes are obtained by making a surface initially and surface is made into the volume, soil properties are added and the soil assigned to the volume respectively.

Step 8: Now the soil volumes required for the generation of model is made and geocell is to be installed in the geocell fill soil so as to do it, with the help of “Import Structures” tab in “Structures” mode, “example_square_tube_1*1*1.3ds” file is selected and dimensions of the of the geocell is entered in the 3 directions and position co-ordinate of the geocell is also entered so that it is obtained at the appropriate place. Using “Geogrids” set in “Show materials” tab “New” option is selected and EA value of geocell is entered and geocell is created in the geogrids tab.

Step 9: By right clicking on the geocell in the geogrid option the appropriate material is selected and assigned to imported structure. Geocell obtained has two interfaces namely positive interface and negative interface. Negative interface is generated inside the geocell and soil inside the geocell is assigned to the negative interface and similarly for positive interface which is generated outer side of the geocell outside soil is allotted to it. Using "Array" option in the structures mode geocells are extended in x and y directions with a perfect spacing and no. of geocells that are to be copied. Firstly surrounding part is made and finally interior part of it is made so as for easy generation of geocells. Similarly for each layer with the help of a geocell and use of array structural elements at the required co-ordinates are generated.

Step 10: If the retaining wall doesn't consist of surface load then it is proceeded to next step for mesh generation otherwise if consists of load, a surface load is created on the top of the model so for creation of surface load, in "Create load" tab "Create surface load" option is selected and the co-ordinates of the surface are entered and the appropriate load is applied in the negative z-direction and after application the whole retaining wall model is generated and it is proceeded to next step for mesh generation.

Step 11: In the "Mesh" mode, "Generate Mesh" option is selected and appropriate mesh is generated. After generation of the mesh to view mesh, "View mesh" option is selected and using "Select point for curves" a point is selected where the analysis of the retaining wall is to be done.

Step 12: As no water level is present in the model, the mode "Water levels" is skipped and advanced to mode "Staged construction" in this two phases are generated, initial phase is to check whether the model prepared is stable or not and other phase known as Phase 1 is made to find out the factor of safety of the model.

Step 13: In the "Initial Phase" some information should be provided they are: Calculation type – Gravity loading, Loading type – Staged construction, Pore pressure calculation – phreatic,

$\sum M_{weight} = 1.00$; and in the “Phase 1” considerations taken are: Calculation type – Safety, Loading type – Incremental multipliers, $M_{sf} = 0.1$

Step 14: So by this generation of the model, mesh generation and initialization of phases are done and only the calculation phase is remained. “Calculate” option is present in the “Staged Construction” mode by clicking it starts the calculation part in which after execution of the Initial phase, Phase 1 will get started and Phase 1 will be the continuation of the Initial phase.

Step 15: Completion of the calculation phase gives out result obtained from “View Calculation results” tab which opens the output of the project in which results regarding the retaining wall can be known such as displacements, stresses, strains, factor of safety, etc. From the obtained results analysis of the project can be done.

Step 16: Similarly steps 1 to steps 15 are made for the different facing angles of geocell retaining wall for different conditions of loading and for different patterns. The obtained results from all the models are collected and analyzed.

- Based on the above many models are generated in which they include: facing angles of 60^0, 70^0, 80^0 and 90^0 with respect to horizontal respectively in addition with conditions of without structural element and no load, with structural element and no load, with structural element and with a surface load of 100 kN/m^2 and with structural element and with a surface load of 150 kN/m^2. In addition to this some layers are also generated including structural element no load and with load of 100 kN/m^2 and 150 kN/m^2 respectively.

4.2 MODELS GENERATED IN PLAXIS 3D WITH DIFFERENT FACING ANGLES WITH RESPECT TO HORIZONTAL

- The basic dimensions generated in all the retaining wall models are 6 m * 4 m * 2.4 m which consists of three different soil materials.
- Geocell retaining wall are generated with respect to horizontal making angles of 60^0, 70^0, 80^0 and 90^0. The mesh generated in all the cases is Medium mesh. Same mesh has been generated so as to know the results among the other retaining walls may be compared and to maintain accuracy.

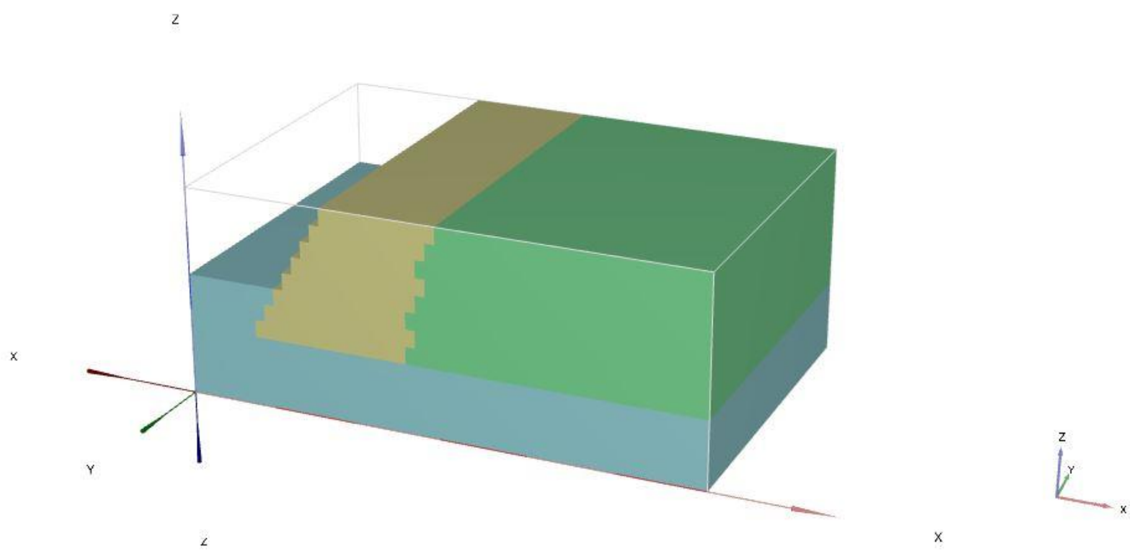


Fig. 4.1: Retaining wall model inclined with facing angle making 60^0 with horizontal with no geocell element and no surface load generated in PLAXIS 3D

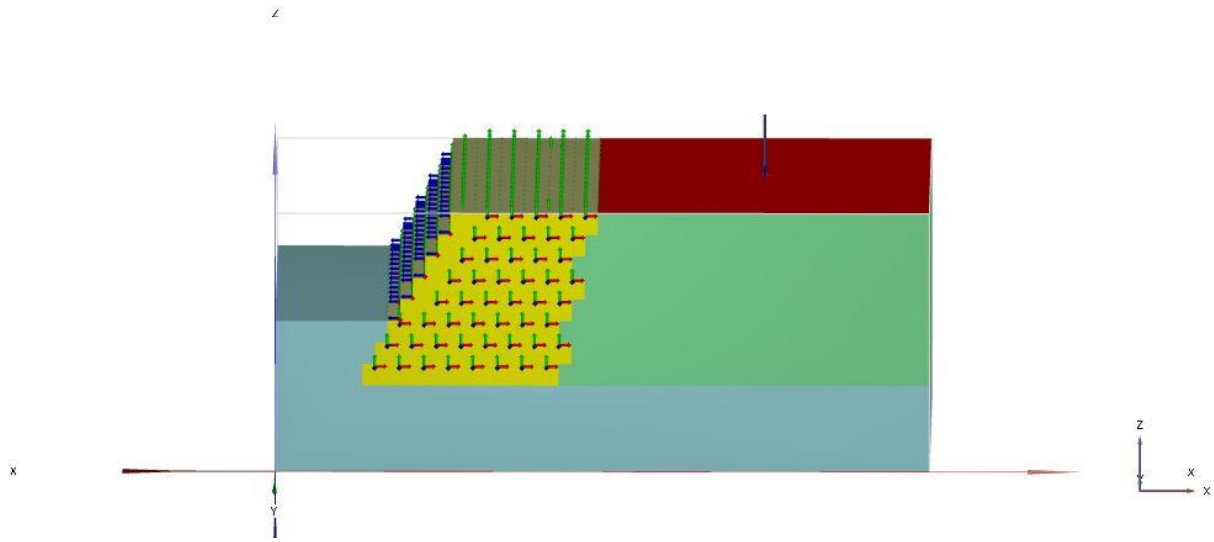


Fig. 4.2: Geocell reinforced retaining wall model inclined with facing angle making 60^0 with horizontal with surface load generated in PLAXIS 3D

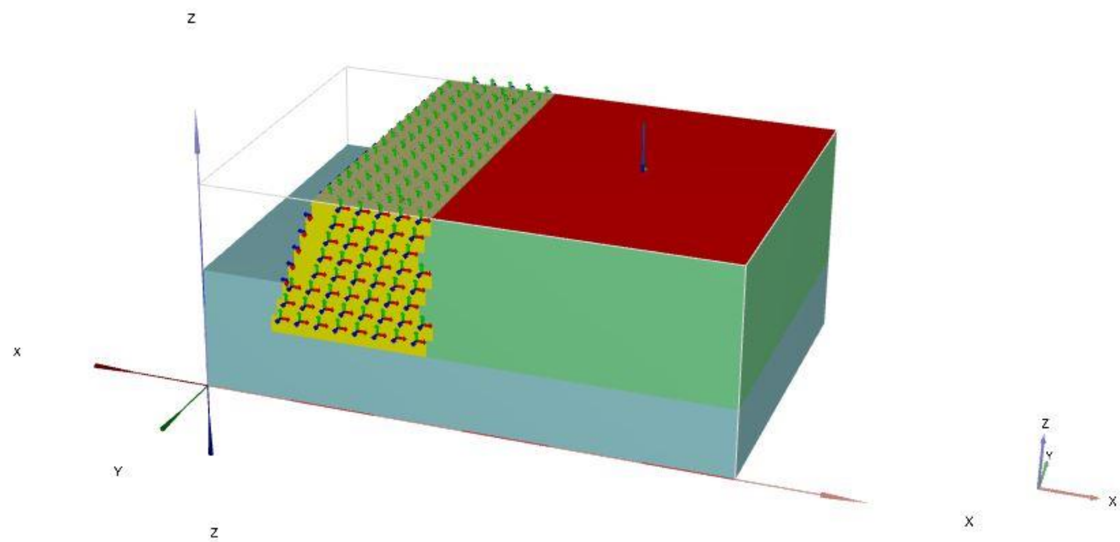


Fig. 4.3: Geocell reinforced retaining wall model inclined with facing angle making 70^0 with horizontal with surface load generated in PLAXIS 3D

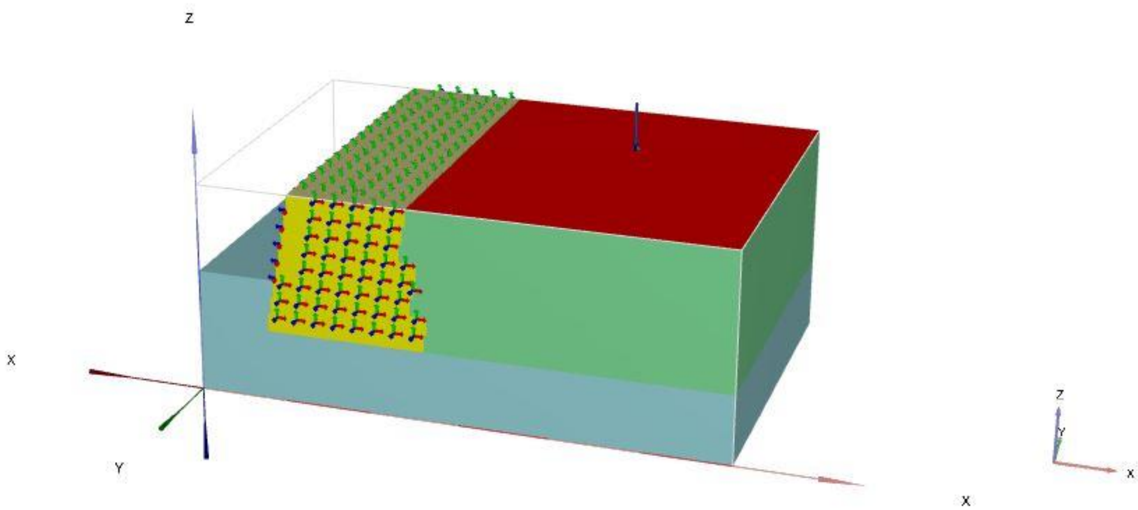


Fig. 4.4: Geocell reinforced retaining wall model inclined with facing angle making 80^0 with horizontal with surface load generated in PLAXIS 3D

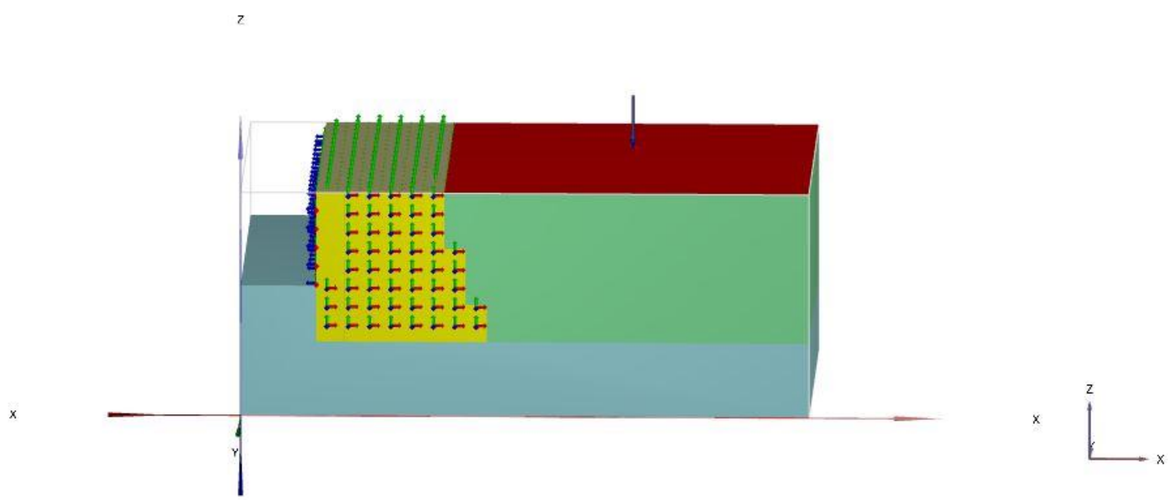


Fig. 4.5: Geocell reinforced retaining wall model inclined with facing angle making 90^0 with horizontal with surface load generated in PLAXIS 3D

4.3 RESULTS OBTAINED FROM PLAXIS 3D AFTER ANALYSIS OF RETAINING WALL MODELS

- Retaining wall inclined at an angle of 60^0 with respect to horizontal without structural element and with no surface load acting load on it.

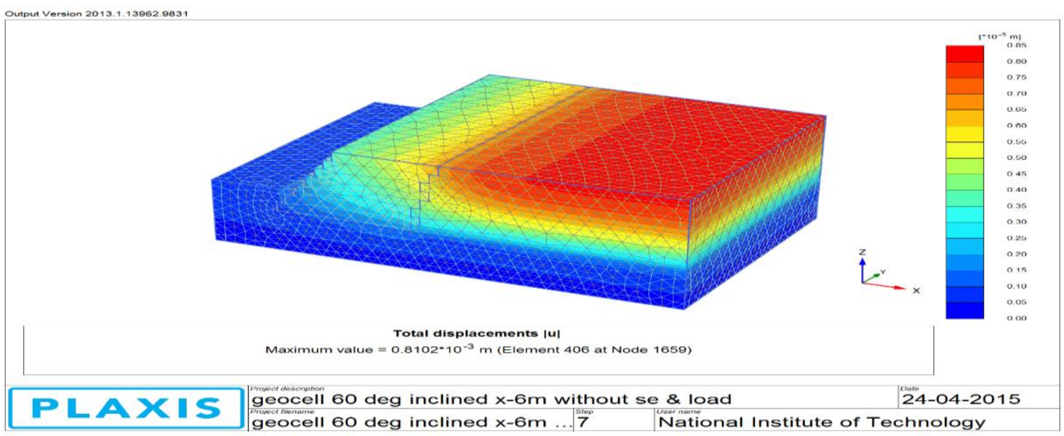
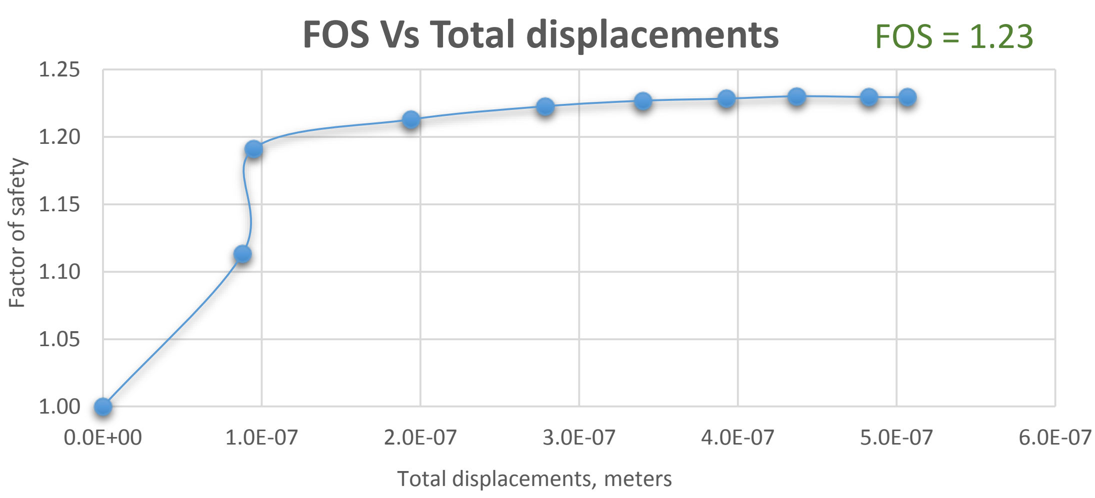


Fig. 4.6: Total displacements value of 60^0 inclined model without geocell element and without surface load



Graph 4.1: FOS Vs Total displacements curve for 60^0 inclined model without geocell element and without surface load

The results obtained from the above analysis are:

i. Total displacements = 0.81 mm

ii. Factor of safety = 1.23

- Retaining walls inclined at an angle of 70^0, 80^0 and 90^0 with respect to horizontal without structural element and with no surface load acting load on it, got failed as they are not stable without any support of structural element so total displacements and factor of safety for these 3 retaining walls are not achieved.

- Retaining wall inclined at an angle of 60^0 with respect to horizontal with structural element and with no surface load acting on it.

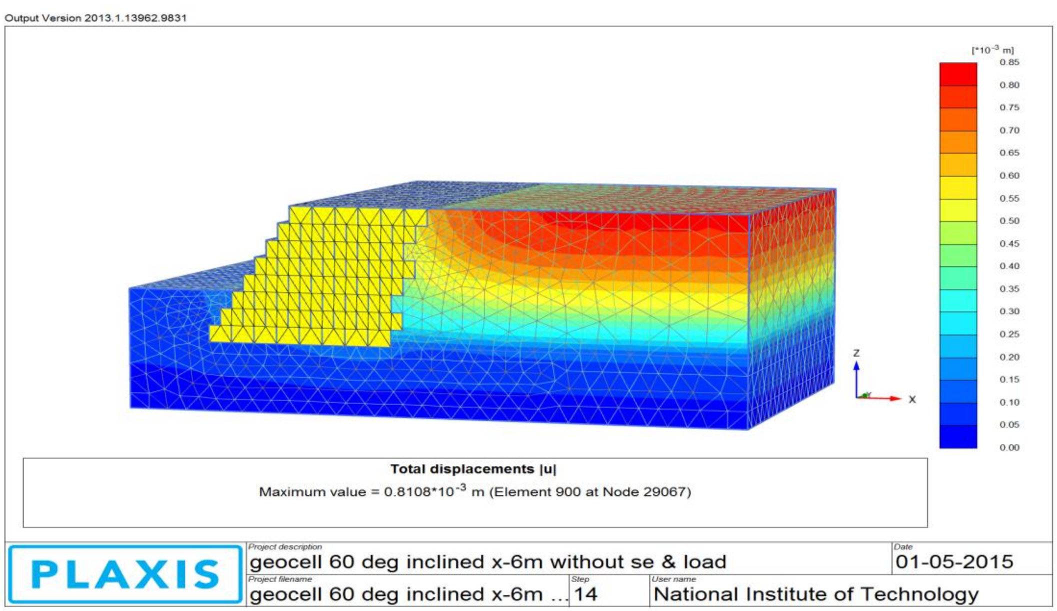
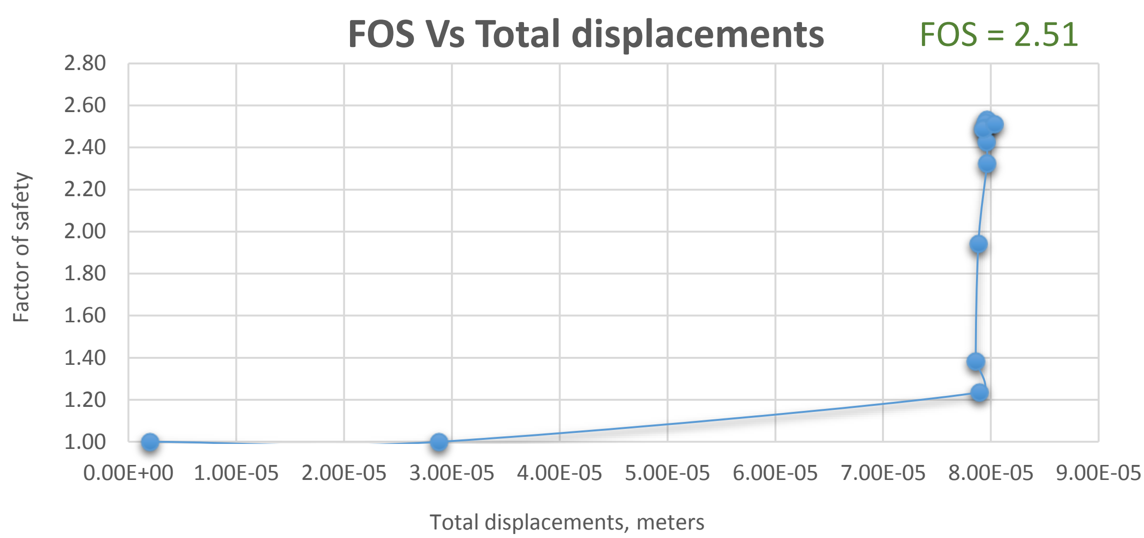


Fig. 4.7: Total displacements value of 60^0 inclined model with geocell element and without surface load



Graph 4.2: FOS Vs Total displacements curve for 60^0 inclined model with geocell element and without surface load

The results obtained from the analysis are:

i. Total displacements = 0.81 mm

ii. Factor of safety = 2.51

➢ Retaining wall inclined at an angle of 70^0 with respect to horizontal with structural element and with no surface load acting on it.

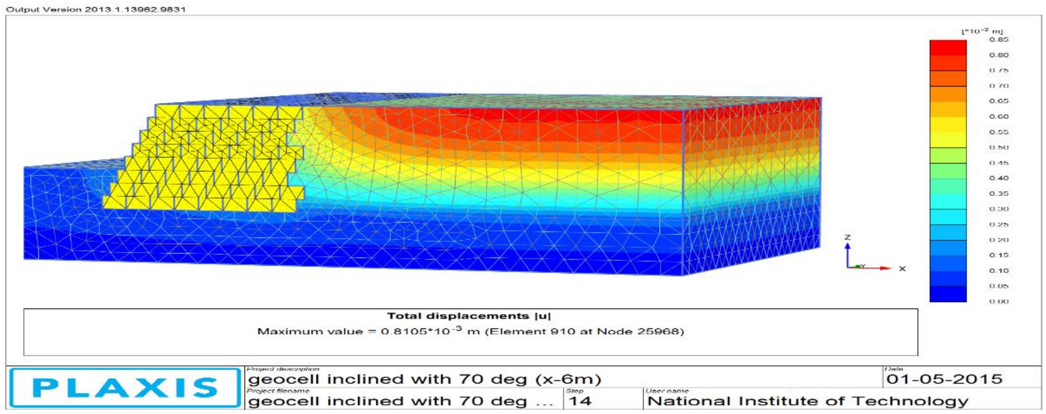
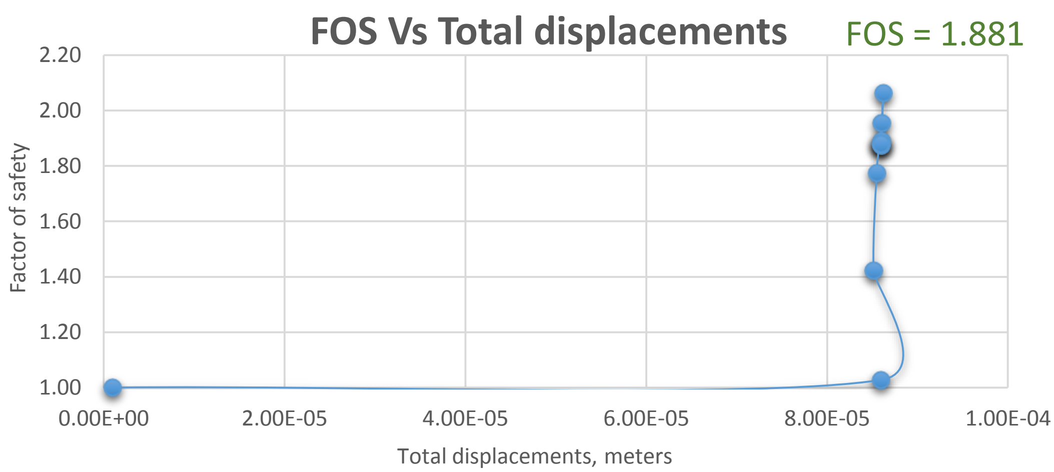


Fig. 4.8: Total displacements value of 70^0 inclined model with geocell element and without surface load



Graph 4.3: FOS Vs Total displacements curve for 70^0 inclined model with geocell element and without surface load

The results obtained from the analysis are:

i. Total displacements = 0.81 mm

ii. Factor of safety = 1.881

➢ Retaining wall inclined at an angle of 80^0 with respect to horizontal with structural element and with no surface load acting on it.

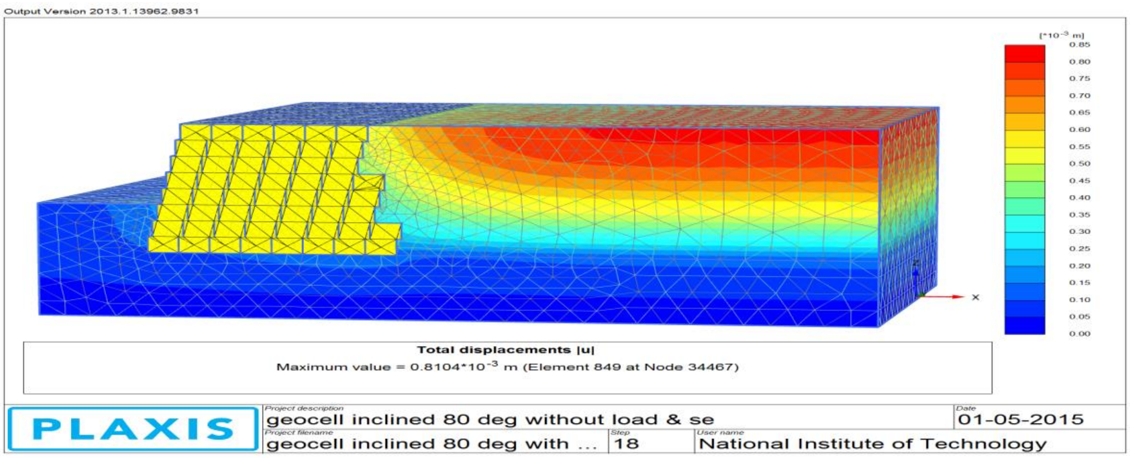
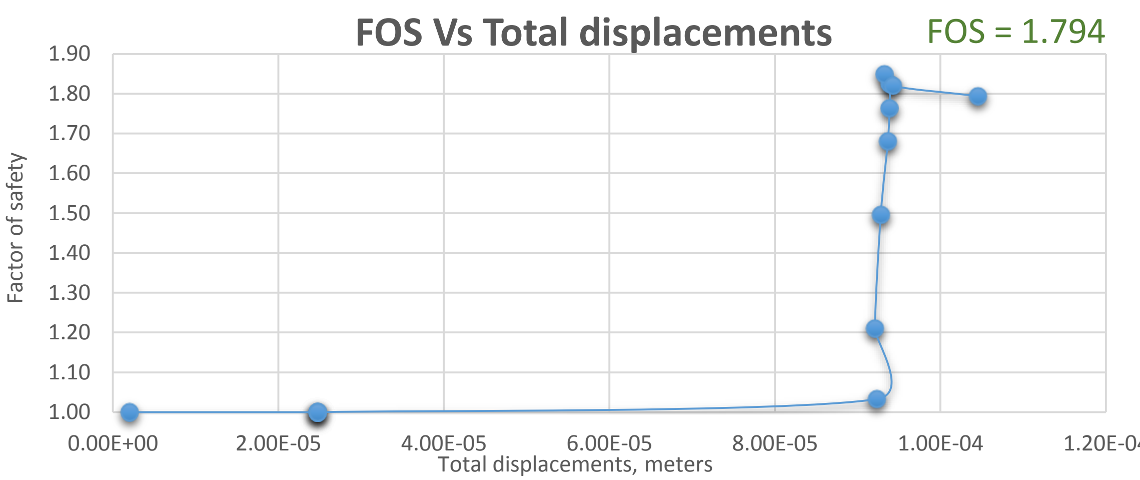


Fig. 4.9: Total displacements value of 80^0 inclined model with geocell element and without surface load



Graph 4.4: FOS Vs Total displacements curve for 80^0 inclined model with geocell element and without surface load

The results obtained from the analysis are:

i. Total displacements = 0.81 mm

ii. Factor of safety = 1.794

➢ Retaining wall inclined at an angle of 90^0 with respect to horizontal with structural element and with no surface load acting on it.

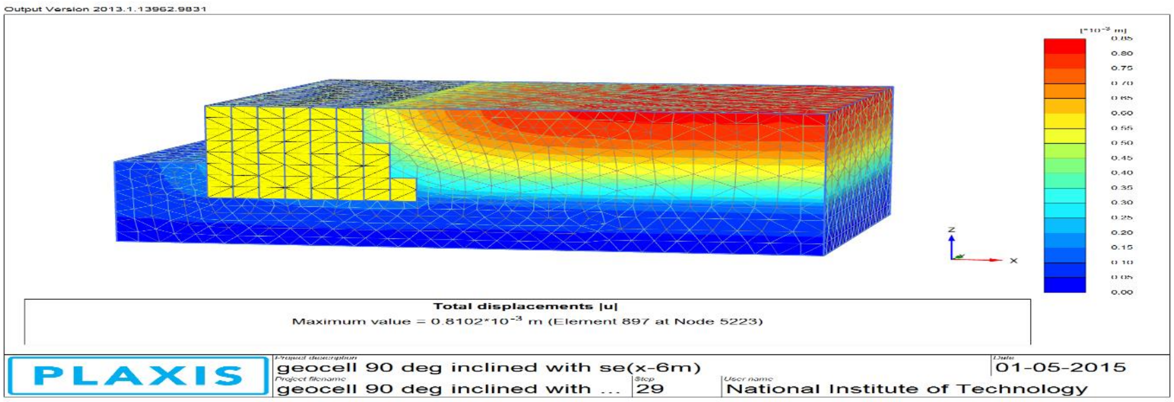
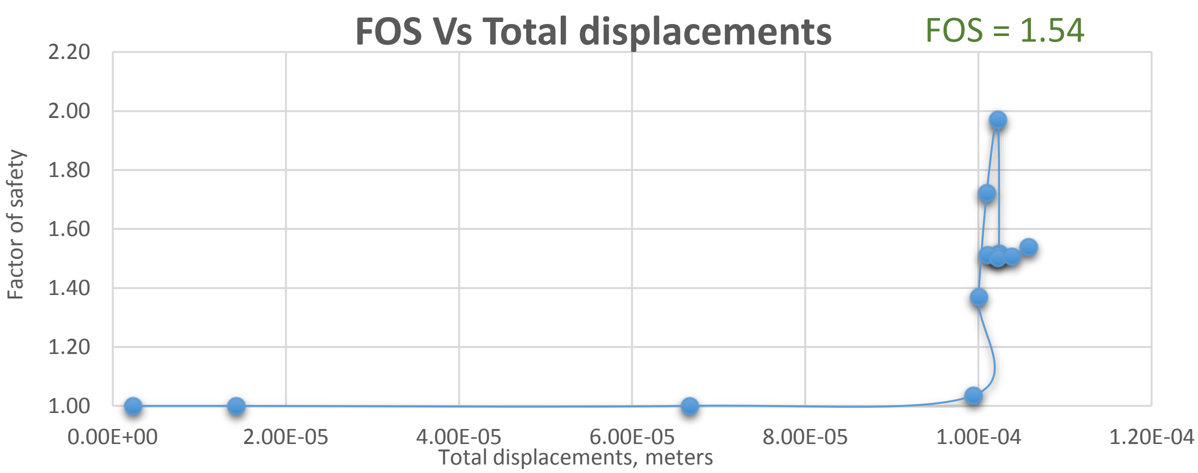


Fig. 4.10: Total displacements value of 90^0 inclined model with geocell element and without surface load



Graph 4.5: FOS Vs Total displacements curve for 90^0 inclined model with geocell element and without surface load

The results obtained from the analysis are:

i. Total displacements = 0.81 mm

ii. Factor of safety = 1.54

Table 4.1: Respective values of displacements and FOS of different facing angles consisting of geocell element and without surface load

Facing angle w.r.t horizontal	Mesh generated	Displacements (mm)	FOS
60^0	Medium	0.81	2.51
70^0	Medium	0.81	1.881
80^0	Medium	0.81	1.794
90^0	Medium	0.81	1.54

- The above values represents the displacements and FOS of retaining wall with different angles without any surface load on it. So from the results it is clear that displacements in all the 4 cases are same and all the models are stable.
- But comparison of FOS makes us clear that the retaining wall making an angle of 60^0 with respect to horizontal possess more factor of safety compared to other retaining wall models.
- This is due to because of less inclination with respect to horizontal which cannot get easily collapsed and as there is no surface load acting, which gives more factor of safety compared to other results.
- So the final result that can be drawn from the above table is that the retaining wall inclined at an angle of 60^0 is more stable when there is no surface load acting on it.

➢ Retaining wall inclined at an angle of 60^0 with respect to horizontal with structural element and with surface load of $100kN/m^2$ acting on it.

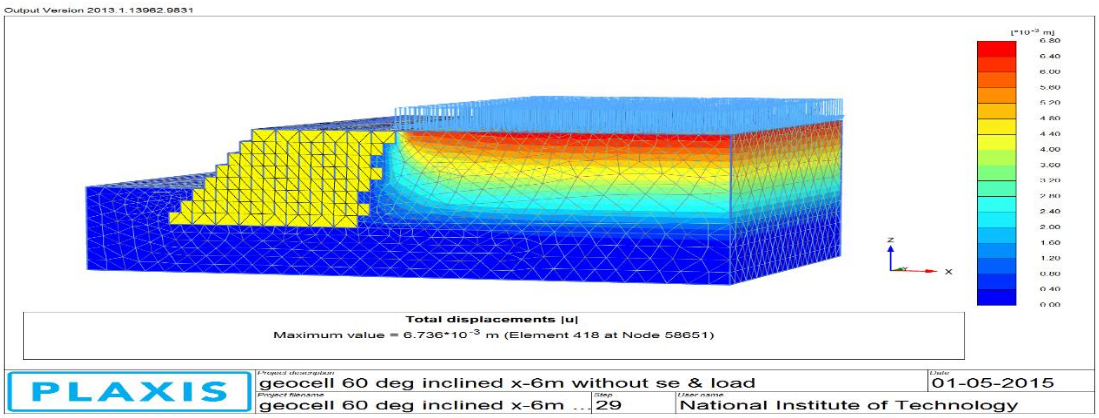
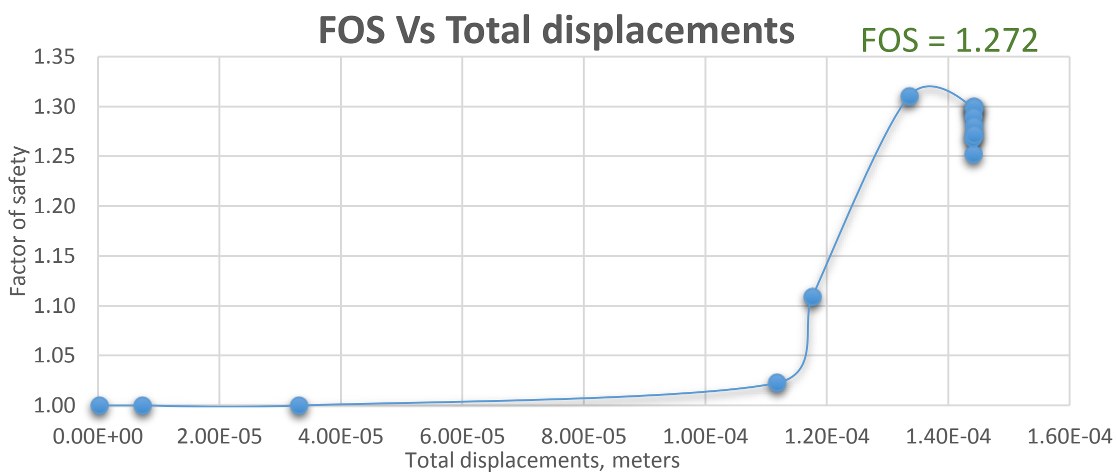


Fig. 4.11: Total displacements value of 60^0 inclined model with geocell element and with surface load of $100kN/m^2$



Graph 4.6: FOS Vs Total displacements curve for 60^0 inclined model with geocell element and with surface load of $100kN/m^2$

The results obtained from the analysis are:

i. Total displacements = 6.736 mm

ii. Factor of safety = 1.272

➢ Retaining wall inclined at an angle of 70^0 with respect to horizontal with structural element and with surface load of $100kN/m^2$ acting on it.

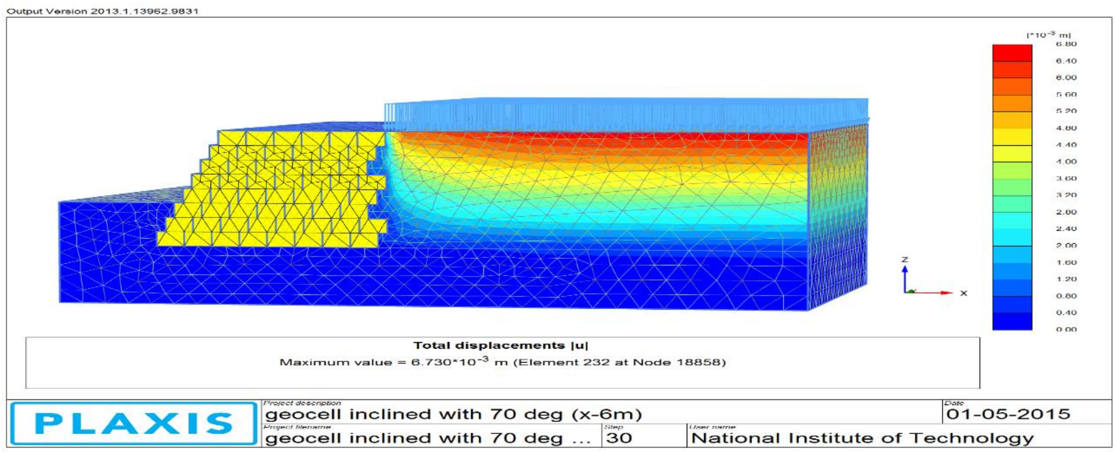
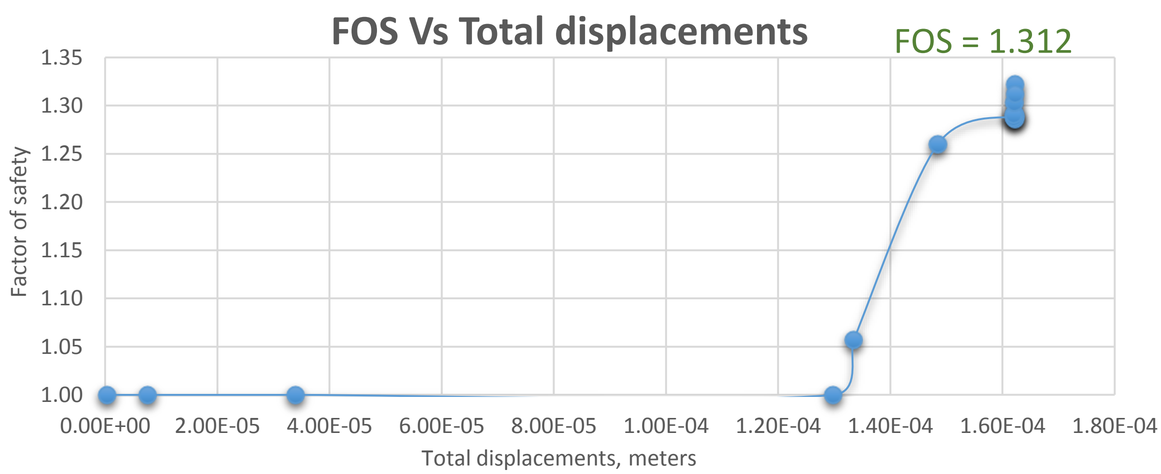


Fig. 4.12: Total displacements value of 70^0 inclined model with geocell element and with surface load of $100kN/m^2$



Graph 4.7: FOS Vs Total displacements curve for 70^0 inclined model with geocell element and with surface load of $100kN/m^2$

The results obtained from the analysis are:

i. Total displacements = 6.73 mm

ii. Factor of safety = 1.312

- Retaining wall inclined at an angle of 80^0 with respect to horizontal with structural element and with surface load of $100kN/m^2$ acting on it.

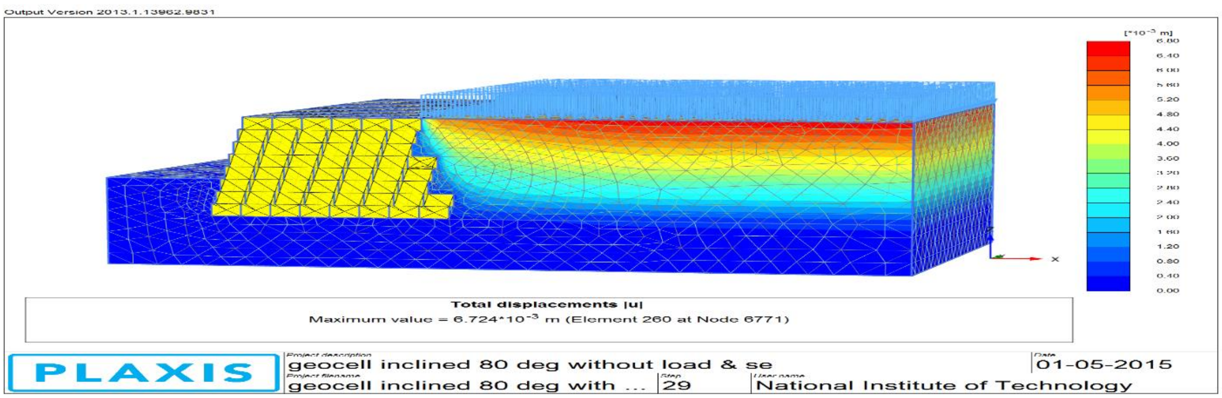
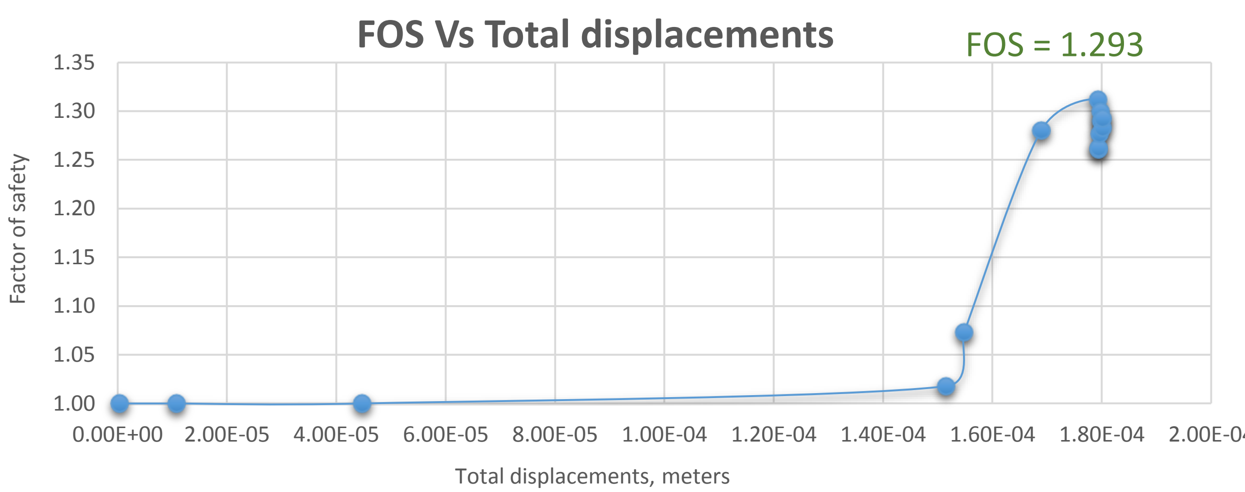


Fig. 4.13: Total displacements value of 80^0 inclined model with geocell element and with surface load of $100kN/m^2$



Graph 4.8: FOS Vs Total displacements curve for 80^0 inclined model with geocell element and with surface load of $100kN/m^2$

The results obtained from the analysis are:

i. Total displacements = 6.724 mm

ii. Factor of safety = 1.293

➢ Retaining wall inclined at an angle of 90^0 with respect to horizontal with structural element and with surface load of $100kN/m^2$ acting on it.

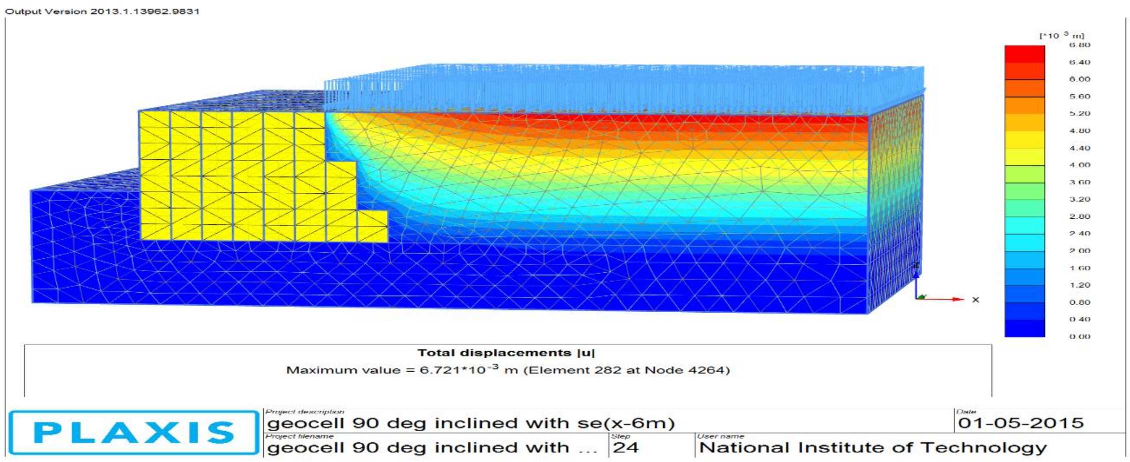
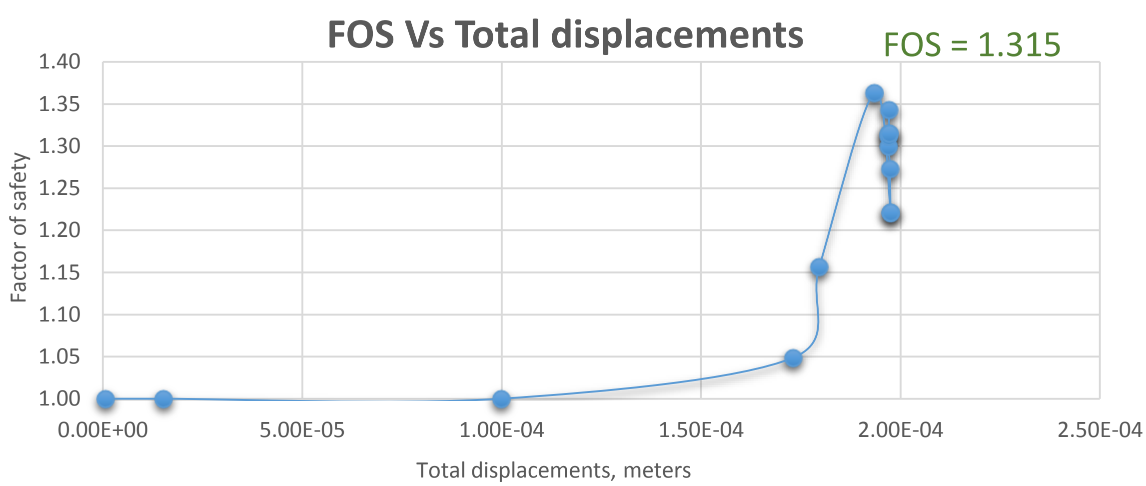


Fig. 4.14: Total displacements value of 90^0 inclined model with geocell element and with surface load of $100kN/m^2$



Graph 4.9: FOS Vs Total displacements curve for 90^0 inclined model with geocell element and with surface load of $100kN/m^2$

The results obtained from the analysis are:

i. Total displacements = 6.721 mm

ii. Factor of safety = 1.315

Table 4.2: Respective values of displacements and FOS of different facing angles consisting of geocell element and with surface load of 100kN/m^2

Facing angle w.r.t horizontal	Mesh generated	Displacements (mm)	FOS
60^0	Medium	6.736	1.272
70^0	Medium	6.73	1.312
80^0	Medium	6.724	1.293
90^0	Medium	6.721	1.315

- The above values represents the displacements and FOS of retaining wall with different angles with a surface load of 100kN/m^2 acting on it. So from the results it is clear that displacements in all the 4 cases are nearly equal to each other but comparatively retaining wall inclined with 90^0 gives less displacement and all the models generated are stable.
- But comparison of FOS makes us clear that the retaining walls making an angle of 70^0 and 90^0 with respect to horizontal possess factor of safety of safety equal to 1.31 which is somewhat high compared to other retaining wall models.
- So the final result that can be drawn from the above table is that the retaining wall inclined at an angle of 90^0 is more stable and possess less displacement and more FOS compared to other retaining wall models.

➢ Retaining wall inclined at an angle of 60^0 with respect to horizontal with structural element and with surface load of 150kN/m^2 acting on it.

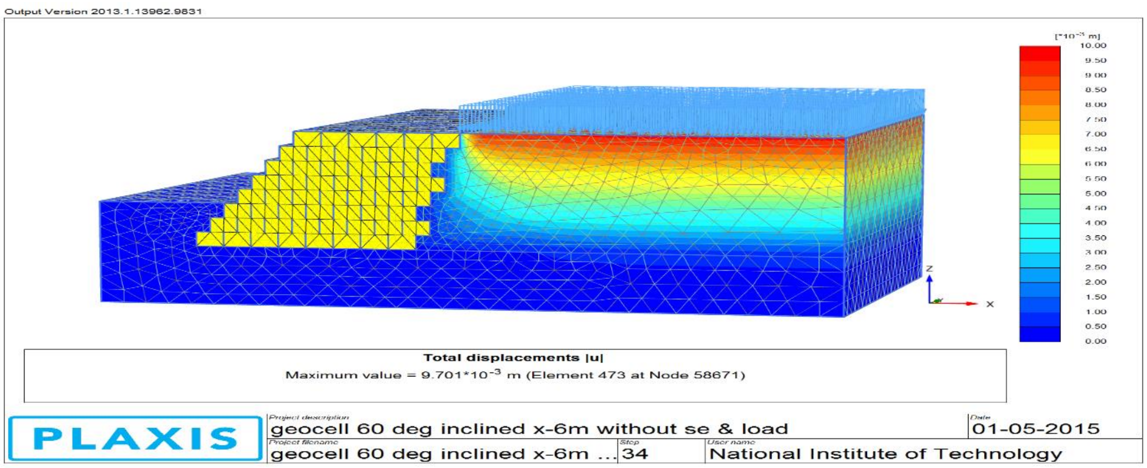
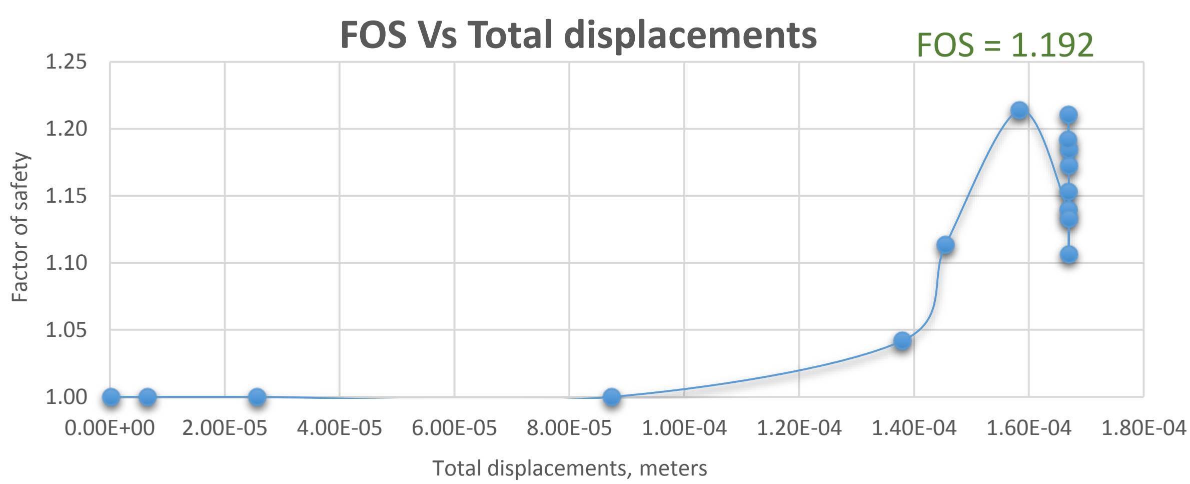


Fig. 4.15: Total displacements value of 60^0 inclined model with geocell element and with surface load of 150kN/m^2



Graph 4.10: FOS Vs Total displacements curve for 60^0 inclined model with geocell element and with surface load of 150kN/m^2

The results obtained from the analysis are:

i. Total displacements = 9.701 mm

ii. Factor of safety = 1.192

➢ Retaining wall inclined at an angle of 70^0 with respect to horizontal with structural element and with surface load of 150kN/m^2 acting on it.

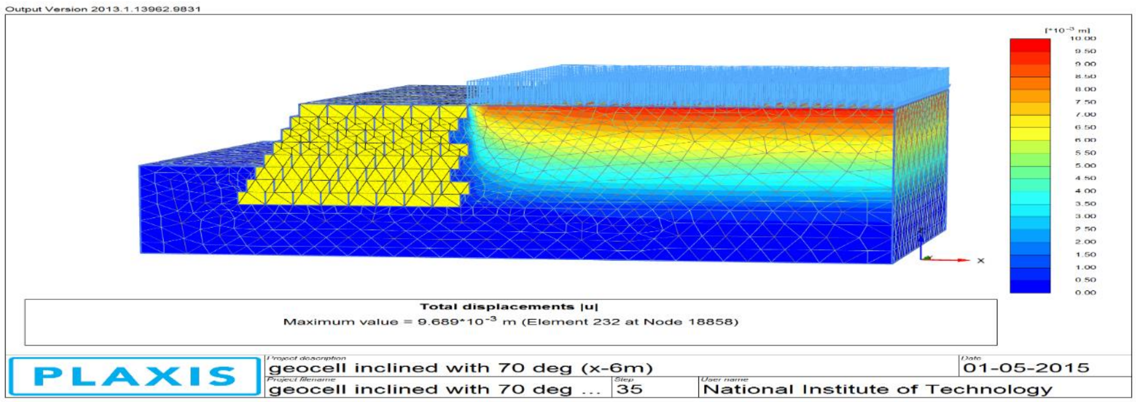
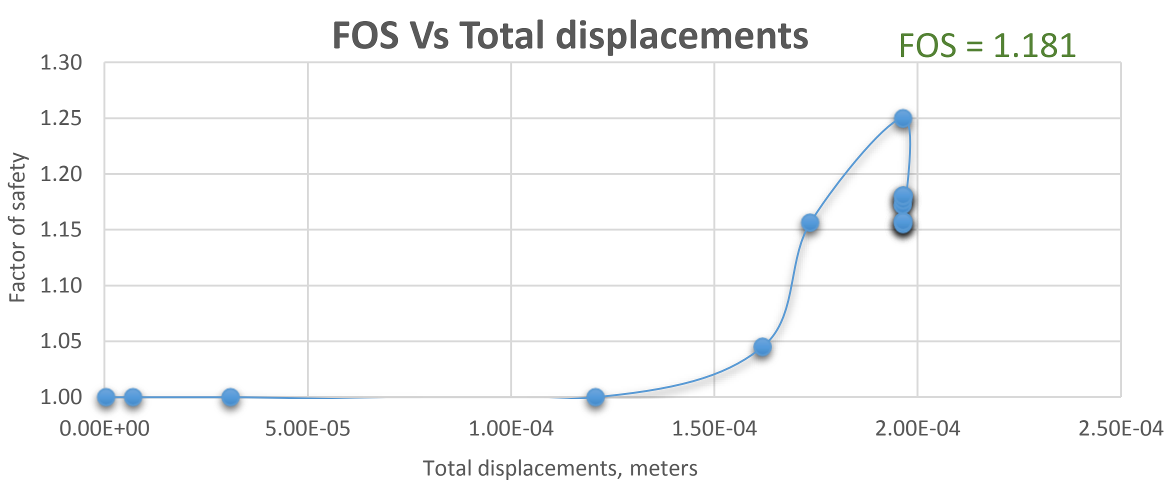


Fig. 4.16: Total displacements value of 70^0 inclined model with geocell element and with surface load of 150kN/m^2



Graph 4.11: FOS Vs Total displacements curve for 70^0 inclined model with geocell element and with surface load of 150kN/m^2

The results obtained from the analysis are:

i. Total displacements = 9.689 mm

ii. Factor of safety = 1.181

- Retaining wall inclined at an angle of 80^0 with respect to horizontal with structural element and with surface load of $150kN/m^2$ acting on it.

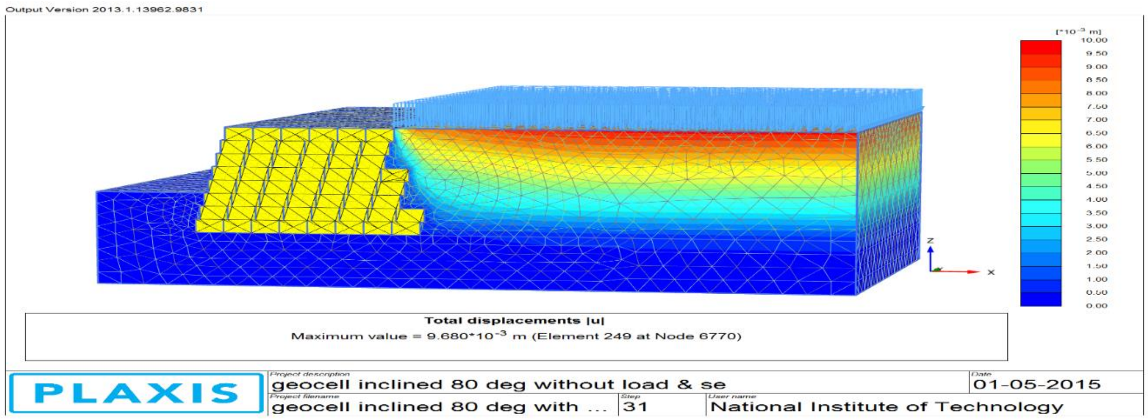
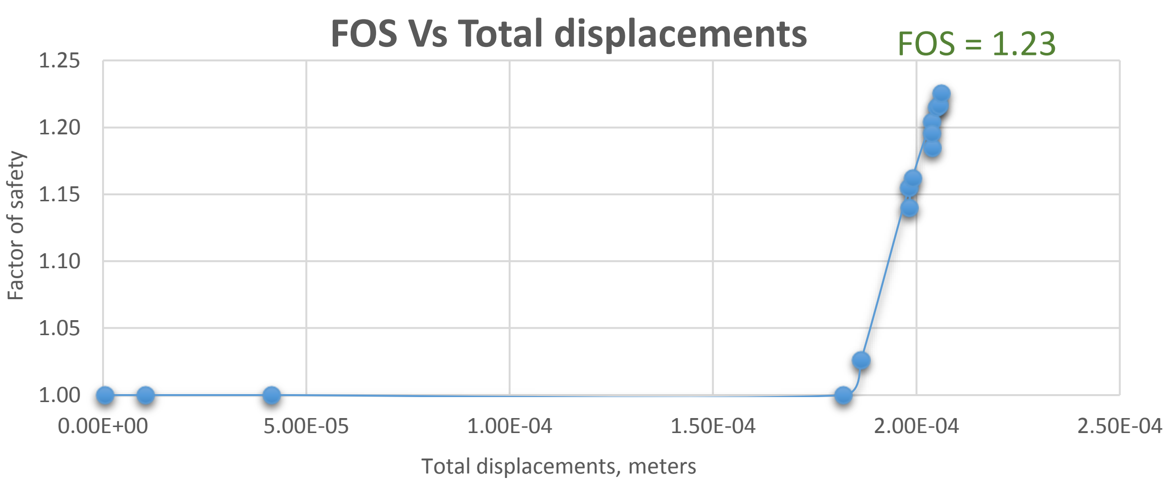


Fig. 4.17: Total displacements value of 80^0 inclined model with geocell element and with surface load of $150kN/m^2$



Graph 4.12: FOS Vs Total displacements curve for 80^0 inclined model with geocell element and with surface load of $150kN/m^2$

The results obtained from the analysis are:

i. Total displacements = 9.68 mm

ii. Factor of safety = 1.23

- Retaining wall inclined at an angle of 90^0 with respect to horizontal with structural element and with surface load of $150kN/m^2$ acting on it.

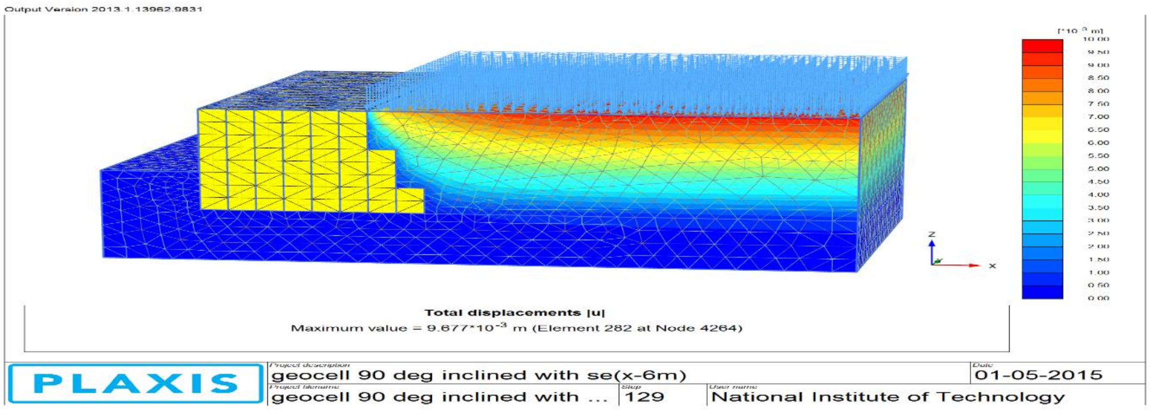
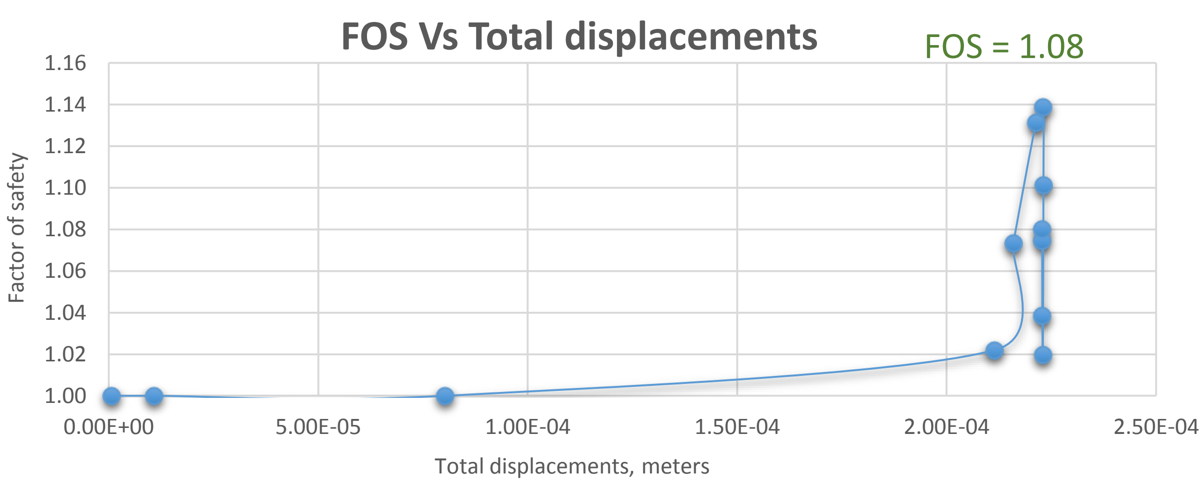


Fig. 4.18: Total displacements value of 90^0 inclined model with geocell element and with surface load of $150kN/m^2$



Graph 4.13: FOS Vs Total displacements curve for 90^0 inclined model with geocell element and with surface load of $150kN/m^2$

The results obtained from the analysis are:

i. Total displacements = 9.677 mm

ii. Factor of safety = 1.08

Table 4.3: Respective values of displacements and FOS of different facing angles consisting of geocell element and with surface load of 150kN/m^2

Facing angle w.r.t horizontal	Mesh generated	Displacements (mm)	FOS
60^0	Medium	9.701	1.192
70^0	Medium	9.689	1.181
80^0	Medium	9.68	1.23
90^0	Medium	9.677	1.08

- The above values represents the displacements and FOS of retaining wall with different angles with a surface load of 150kN/m^2 acting on it. So from the results it is clear that displacements in all the 4 cases are nearly equal to each other but comparatively retaining walls inclined with 80^0 and 90^0 gives less displacement and all the models generated are stable.
- But comparison of FOS makes us clear that the retaining walls making an angle of 80^0 with respect to horizontal possess factor of safety of safety equal to 1.23 which is higher compared to other retaining wall models.
- The percentage decrease in FOS for 100kN/m^2 to 150 kN/m^2 is described below:

  60^0 retaining wall – 6.29%; 70^0 retaining wall – 9.98%

  80^0 retaining wall – 5.26%; 90^0 retaining wall – 17.87%
- In the case of 100kN/m^2 the difference in displacements and FOS between models 80^0 and 90^0 is very minimal mostly a difference of 0.02, but from the above conclusion and results of 150kN/m^2 it is clear that the retaining wall inclined with 80^0 possess more stability compared to other retaining wall models.
- **The model suggestable for appropriate packing of geocells is *facing angle of 80^0 with respect to horizontal.***

➢ Retaining wall inclined at an angle of 80^0 with the horizontal consisting of equal number of geocells in each layer and with no surface load acting on it.

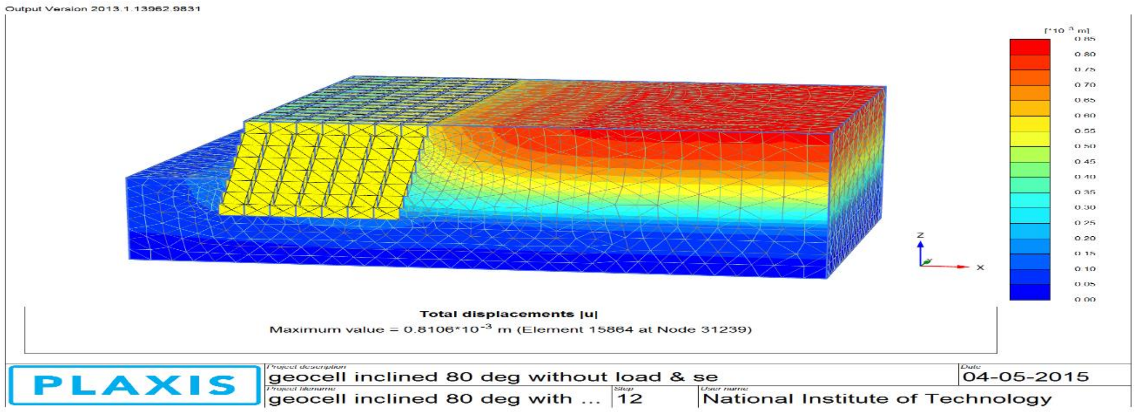
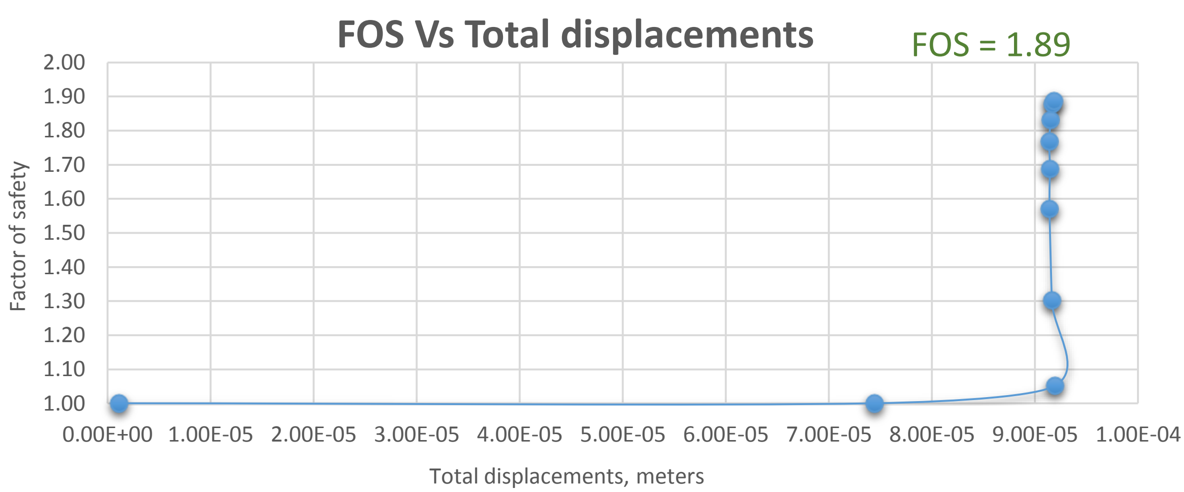


Fig. 4.19: Total displacements value of equal number of geocells in each layer inclined with 80^0 with geocell element and without surface load



Graph 4.14: FOS Vs Total displacements curve for equal number of geocells in each layer inclined with 80^0 with geocell element and without surface load

The results obtained from the analysis are:

i. Total displacements = 0.81 mm

ii. Factor of safety = 1.89

- Retaining wall inclined at an angle of 80^0 with the horizontal consisting of equal number of geocells in each layer and with surface load of $100kN/m^2$ acting on it.

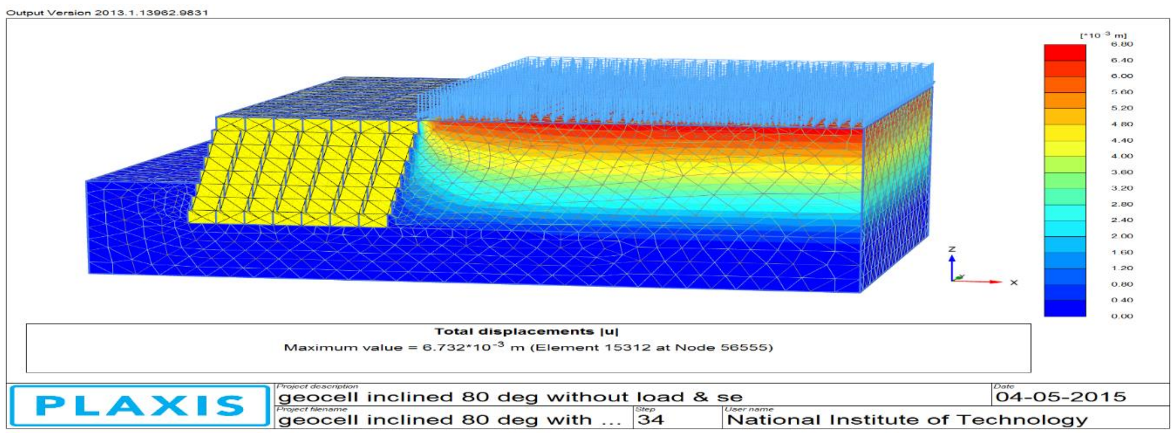
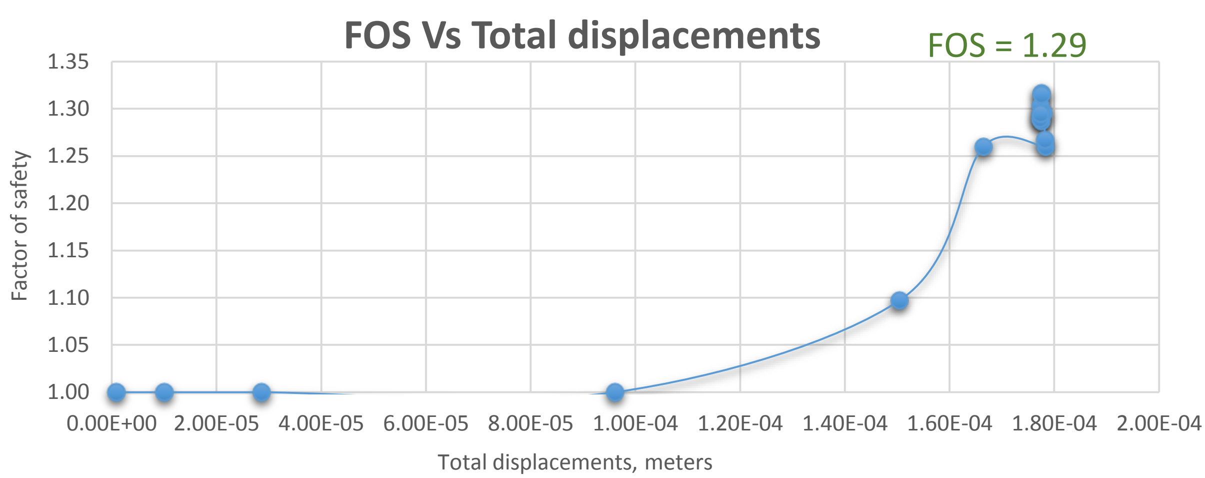


Fig. 4.20: Total displacements value of equal number of geocells in each layer inclined with 80^0 with geocell element and with surface load of $100kN/m^2$



Graph 4.15: FOS Vs Total displacements curve for equal number of geocells in each layer inclined with 80^0 with geocell element and with surface load of $100kN/m^2$

The results obtained from the analysis are:

i. Total displacements = 6.732 mm

ii. Factor of safety = 1.29

- Retaining wall inclined at an angle of 80^0 with the horizontal consisting of equal number of geocells in each layer and with surface load of $150kN/m^2$ acting on it.

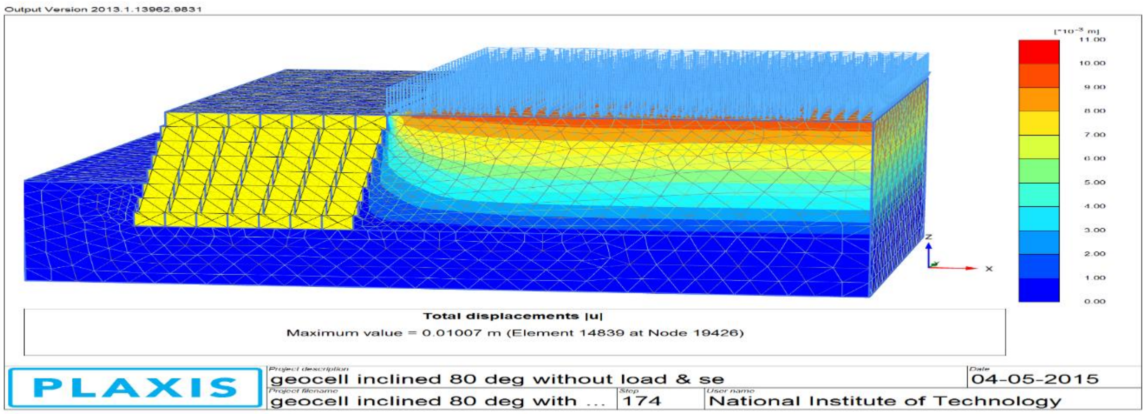
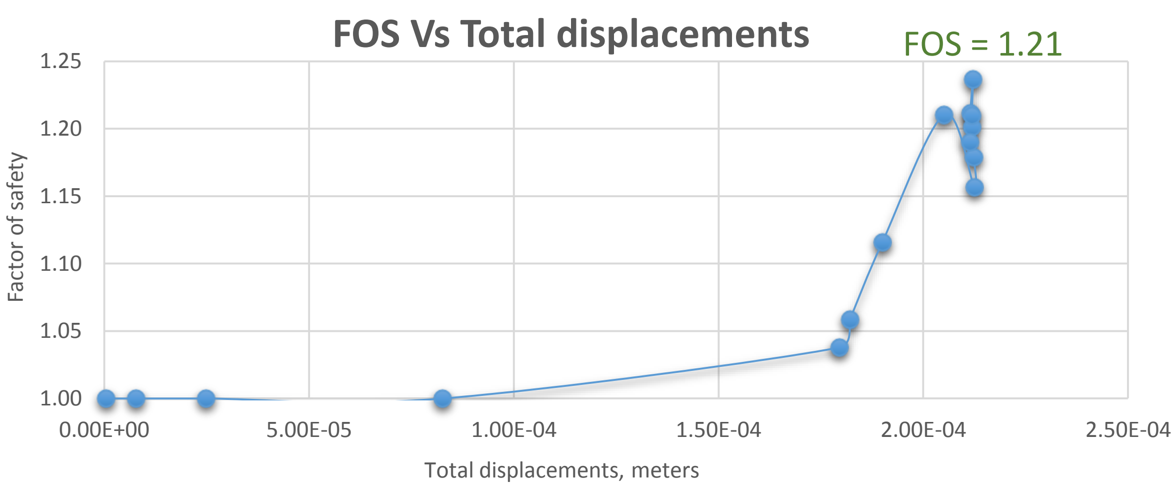


Fig. 4.21: Total displacements value of equal number of geocells in each layer inclined with 80^0 with geocell element and with surface load of $150kN/m^2$



Graph 4.16: FOS Vs Total displacements curve for equal number of geocells in each layer inclined with 80^0 with geocell element and with surface load of $150kN/m^2$

The results obtained from the analysis are:

i. Total displacements = 10.07 mm

ii. Factor of safety = 1.21

- Retaining wall inclined at an angle of 80^0 with the horizontal extended in the top layers so as to prevent wall from tilting with geocell element and with no surface load acting on it.

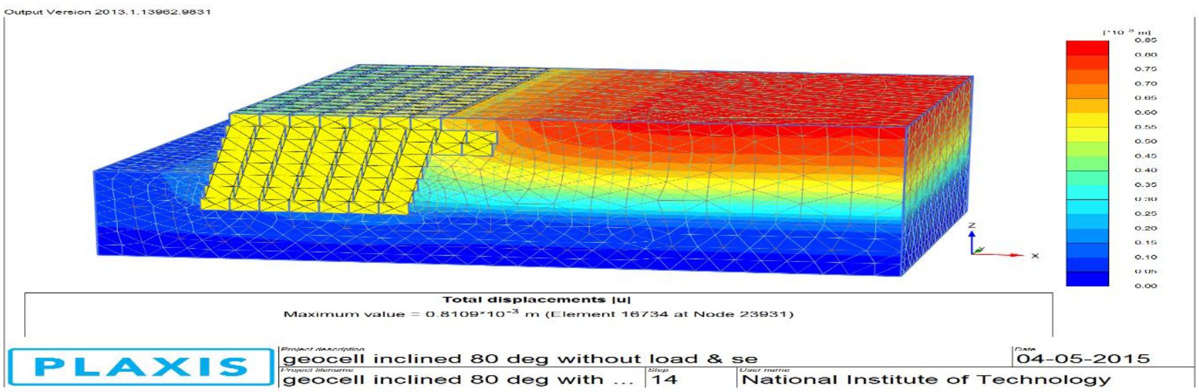
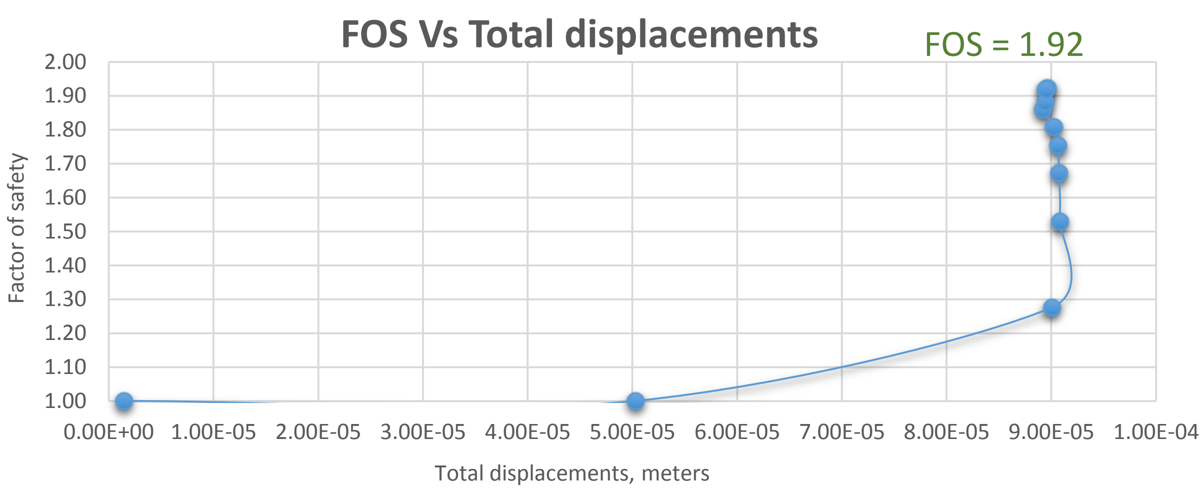


Fig. 4.22: Total displacements value of retaining wall inclined with 80^0 made it to prevent it from tilting with geocell element and without surface load



Graph 4.17: FOS Vs Total displacements curve for retaining wall inclined with 80^0 made it to prevent it from tilting with geocell element and without surface load

The results obtained from the analysis are:

i. Total displacements = 0.81 mm

ii. Factor of safety = 1.92

- Retaining wall inclined at an angle of 80^0 with the horizontal extended in the top layers so as to prevent wall from tilting with geocell element and with surface load of $100kN/m^2$.

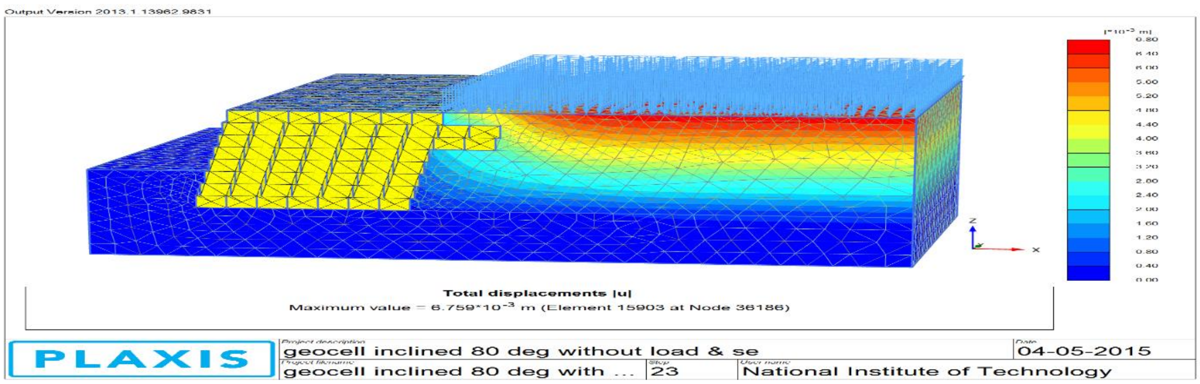
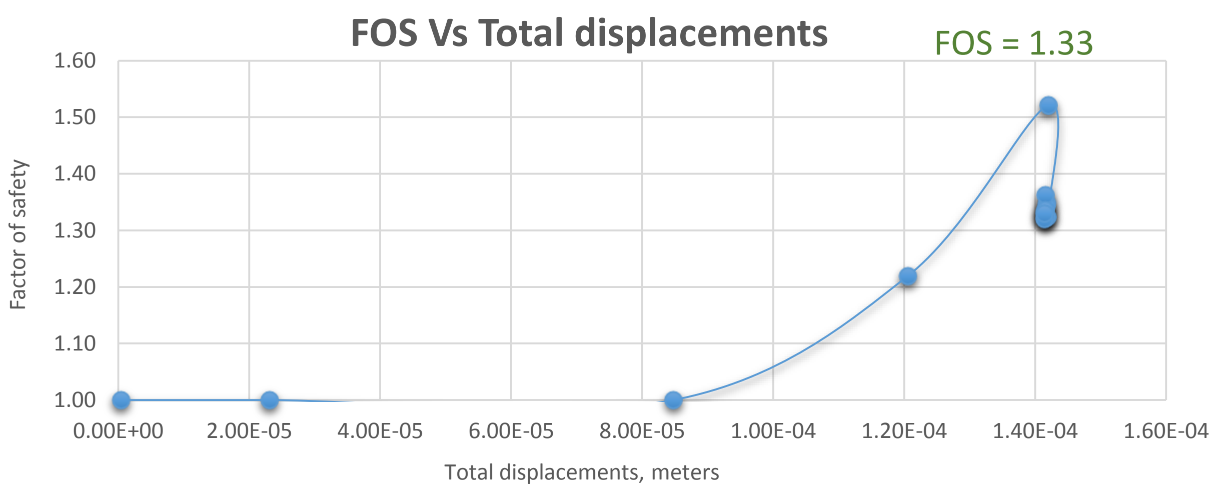


Fig. 4.23: Total displacements value of retaining wall inclined with 80^0 made it to prevent it from tilting with geocell element and with surface load of $100kN/m^2$



Graph 4.18: FOS Vs Total displacements curve for retaining wall inclined with 80^0 made it to prevent it from tilting with geocell element and with surface load of $100kN/m^2$

The results obtained from the analysis are:

i. Total displacements = 6.759 mm

ii. Factor of safety = 1.33

➢ Retaining wall inclined at an angle of 80^0 with the horizontal extended in the top layers so as to prevent wall from tilting with geocell element and with surface load of $150kN/m^2$.

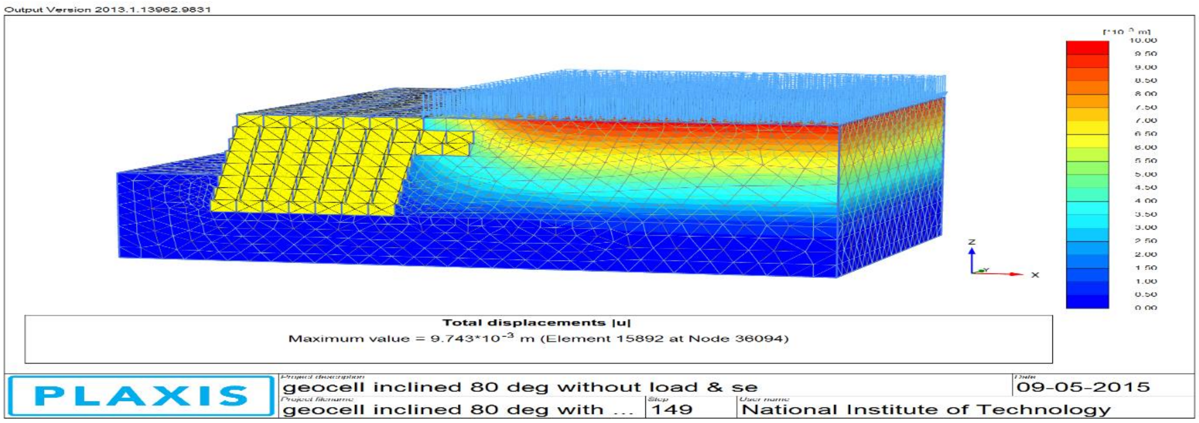
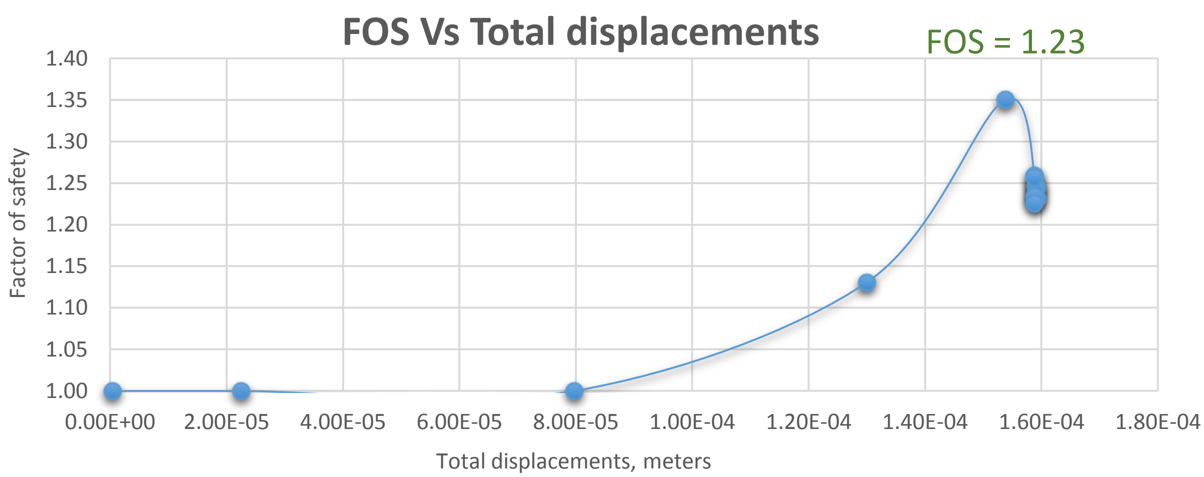


Fig. 4.24: Total displacements value of retaining wall inclined with 80^0 made it to prevent it from tilting with geocell element and with surface load of $150kN/m^2$



Graph 4.19: FOS Vs Total displacements curve for retaining wall inclined with 80^0 made it to prevent it from tilting with geocell element and with surface load of $150kN/m^2$

The results obtained from the analysis are:

i. Total displacements = 9.743 mm

ii. Factor of safety = 1.23

- Retaining wall inclined at an angle of 80^0 with the horizontal extended at particular layers like that of geogrid reinforcement with geocell element and with no surface load.

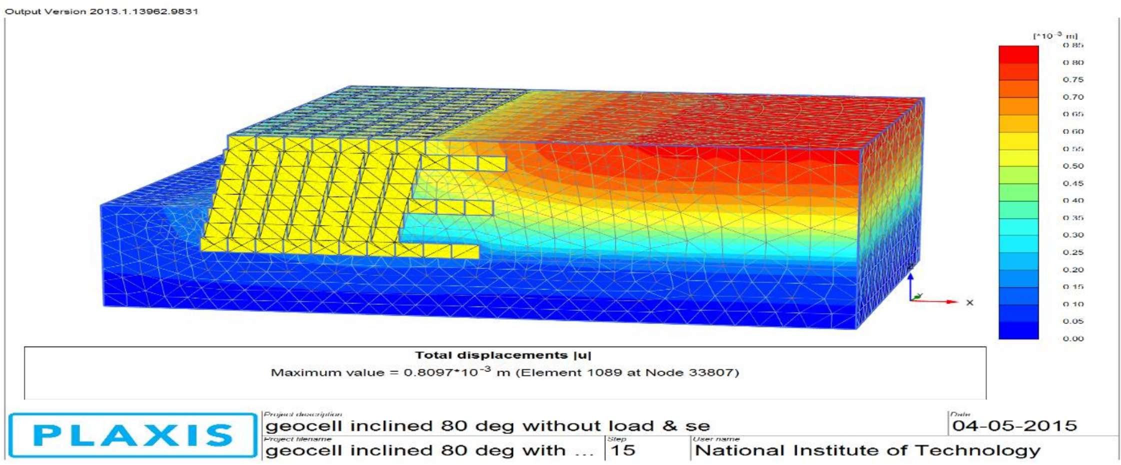
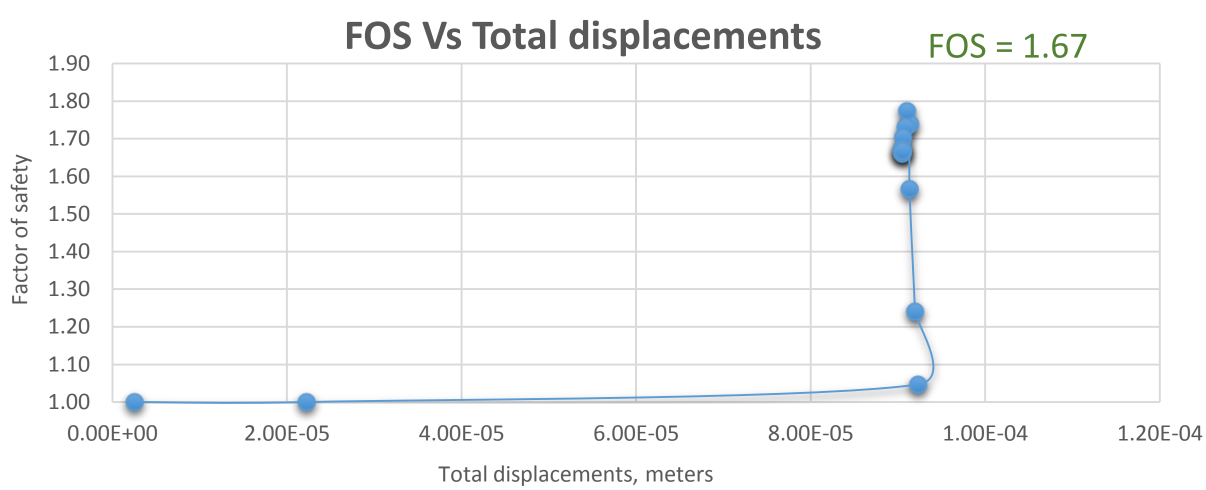


Fig. 4.25: Total displacements value of retaining wall inclined with 80^0 and layers extended like geogrids with geocell element and without surface load



Graph 4.20: FOS Vs Total displacements curve for retaining wall inclined with 80^0 and layers extended like geogrids with geocell element and without surface load

The results obtained from the analysis are:

i. Total displacements = 0.81 mm

ii. Factor of safety = 1.67

- Retaining wall inclined at an angle of 80^0 with the horizontal extended at particular layers like that of geogrid reinforcement with geocell element and with surface load of 100kN/m^2.

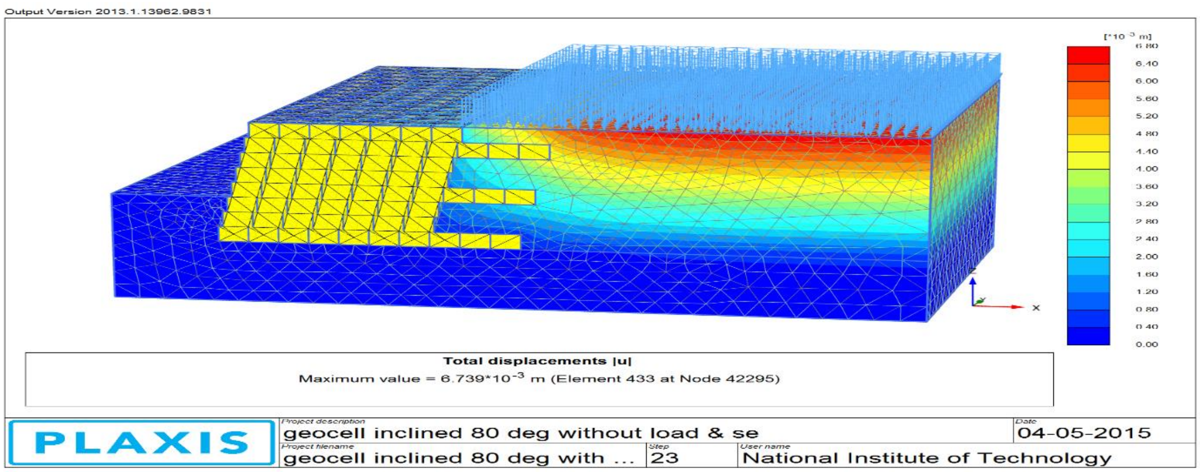
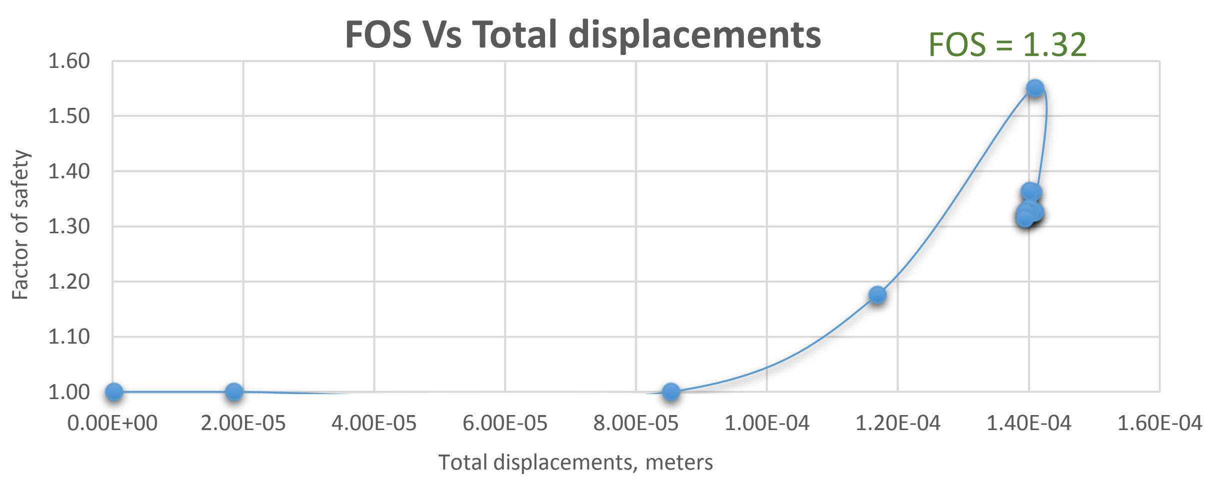


Fig. 4.26: Total displacements value of retaining wall inclined with 80^0 and layers extended like geogrids with geocell element and with surface load of 100kN/m^2



Graph 4.21: FOS Vs Total displacements curve for retaining wall inclined with 80^0 and layers extended like geogrids with geocell element and with surface load of 100kN/m^2

The results obtained from the analysis are:

i. Total displacements = 6.739 mm

ii. Factor of safety = 1.32

➢ Retaining wall inclined at an angle of 80^0 with the horizontal extended at particular layers like that of geogrid reinforcement with geocell element and with surface load of $150kN/m^2$.

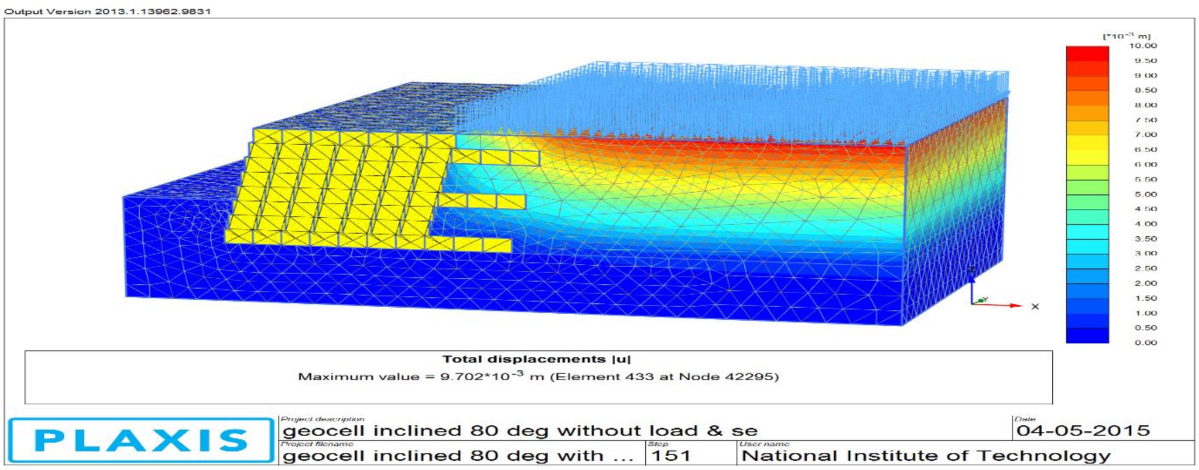
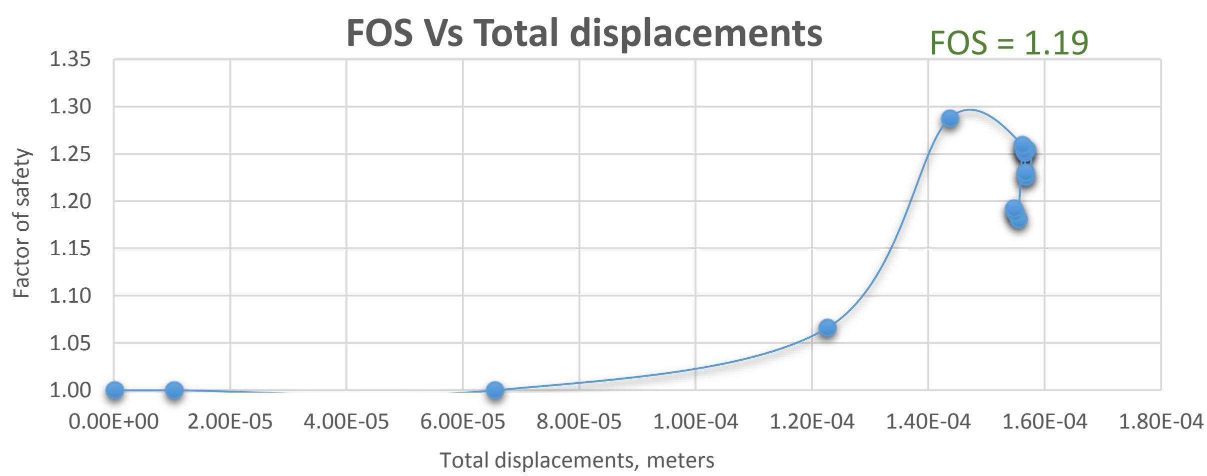


Fig. 4.27: Total displacements value of retaining wall inclined with 80^0 and layers extended like geogrids with geocell element and with surface load of $150kN/m^2$



Graph 4.22: FOS Vs Total displacements curve for retaining wall inclined with 80^0 and layers extended like geogrids with geocell element and with surface load of $150kN/m^2$

The results obtained from the analysis are:

i. Total displacements = 9.702 mm

ii. Factor of safety = 1.19

Table 4.4: Respective values of displacements and FOS of 80^0 inclined model with equal number of geocells in each layer for different loading conditions

Equal number of geocells in each layer:

S .No.	Loading Conditions	Mesh	Displacements (mm)	FOS
1.	No load	Medium mesh	0.81	1.89
2.	100kN/m^2 surface load	Medium mesh	6.732	1.29
3.	150kN/m^2 surface load	Medium mesh	10.07	1.21

Table 4.5: Respective values of displacements and FOS of 80^0 inclined model extended in the top layers so as to prevent wall from tilting for different loading conditions

Prevention of wall from tilting:

S .No.	Loading Conditions	Mesh	Displacements (mm)	FOS
1.	No load	Medium mesh	0.81	1.92
2.	100kN/m^2 surface load	Medium mesh	6.759	1.33
3.	150kN/m^2 surface load	Medium mesh	9.743	1.23

Table 4.6: Respective values of displacements and FOS of 80^0 inclined model extended at particular layers like that of geogrids for different loading conditions

Layers extended at particular intervals like that of geogrid reinforcement:

S .No.	Loading Conditions	Mesh	Displacements (mm)	FOS
1.	No load	Medium mesh	0.81	1.67
2.	100kN/m^2 surface load	Medium mesh	6.739	1.32
3.	150kN/m^2 surface load	Medium mesh	9.702	1.19

- The above three tables gives us the information of displacements and FOS for different loading conditions for three different models.
- In the first one equal number or geocells are used in every layer, the number considered here is 7, an average value is considered. In the second case, second and third layers from the top are extended with 2 extra geocells compared with other layers, so as this helps the retaining wall to prevent it from tilting.
- In the final case, at particular intervals geocells are extended with more number compared to other layers so that the model looks like geogrid reinforcement at particular intervals.
- But among the above three cases, second case provides better stacking of geocell elements and gives better results compared to that of the other two cases.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5. CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSIONS

On the basis of present study and analysis the following conclusions are drawn:

1. When the retaining wall is constructed with the use of geocell element and when there is no external load acting on it, then the retaining wall with lower facing angle with respect to horizontal gives better result, so in our case retaining angle inclined with 60^0 with horizontal gives comparatively good result. But providing facing angle less than 60^0 with respect to horizontal becomes uneconomical because the area covered by geocells will be more and the top surface area gets decreased.
2. With the increase in surface load on the retaining wall the percentage decrease in FOS holds good when the retaining wall is constructed with an angle making 80^0 with respect to horizontal when compared to other retaining walls.
3. From the results obtained, stacking of geocells one upon the other layer is suggestable when the layers are arranged in order with the angle making 80^0 with the horizontal.
4. Three other modifications are made to the final suggested model i.e., equal number in each layer, retaining wall prevention against tilting and alternate layers extended like that of geogrid reinforcement; among the above three modifications tilting gives better results.

5.2 FUTURE SCOPES

The present work may be further extended as following:

1. Soil materials considered in all the generation of models are of same type, further analysis can be done by changing different soil materials.
2. Loading conditions considered in the present analysis is only vertical loading, analysis can be further done based on eccentric loading and even on dynamic loading.

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